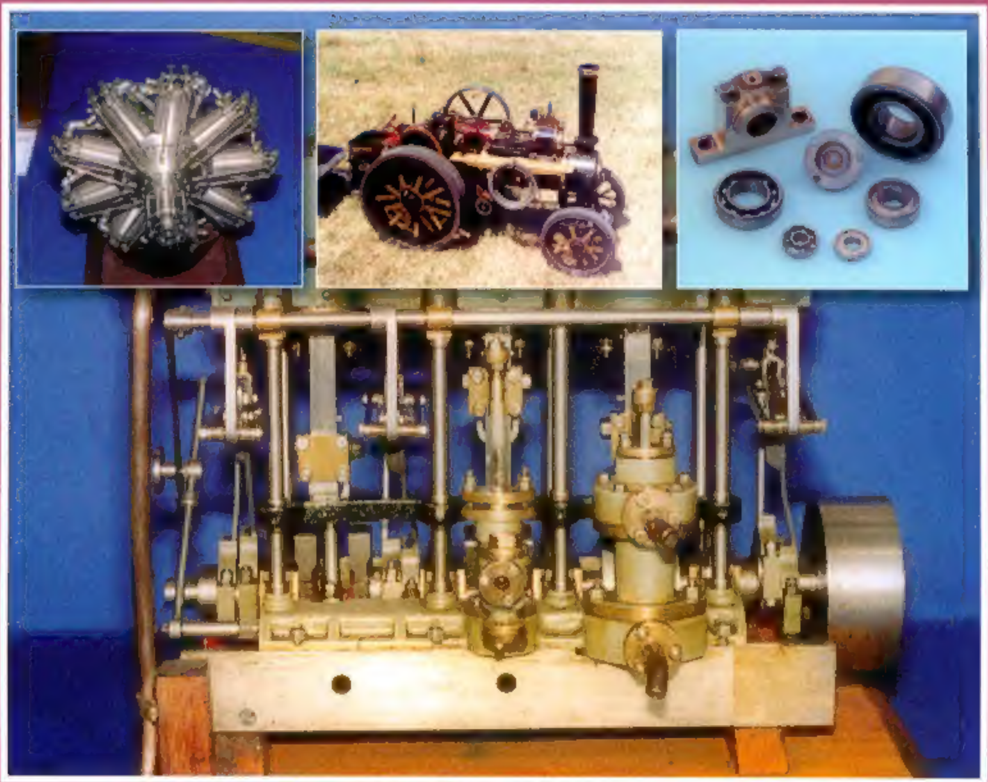
BEARINGS

Alex Weiss



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Bearings

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Contents

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Many unnamed people have built and displayed at exhibitions the high standard of models that have been photographed and used as illustrations in this book. My thanks go to all of them for their superb efforts. It is hoped that they will be able to recognise pictures of their particular works of art.

Finally, I would like to give my heartfelt thanks to my wife for putting up with my obsessiveness in completing this book.

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Introduction

What is a bearing?

It is not easy to define exactly what constitutes a bearing. Clearly any machine that has a moving part connected to a stationary part will require a bearing between the two parts. The same is true for two moving parts that are connected together. For most people, rotating shafts are what spring to mind when thinking about bearings, but in many cases, such as a piston in a cylinder, or slides on a lathe, the two parts rub together in an oscillating linear motion and thus the interface between the two surfaces also needs to be thought of as a bearing. The materials used for their construction must be chosen with the same care as for a rotary bearing. Furthermore, both rotating and oscillating bearings may need to be made steam-, air-, oil- or waterproof by the use of a gland or stuffing box.

Bearings are hard-wearing anti-friction devices and the many different types have an array of anti-friction characteristics, wear rates, speed ranges and load-carrying capacities. As bearings have to permit smooth, low-friction movement between two surfaces, almost all employ some form of lubrication: either oil or grease. Bearings fall into two clear categories: rotary bearings, and linear or oscillating bearings. Both categories can further be divided into two distinct classes: those that use a sliding action and those that

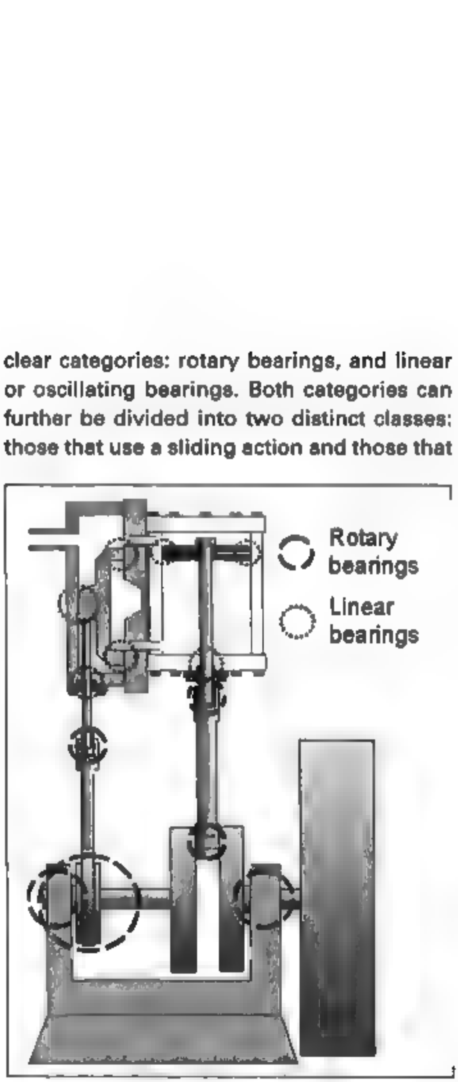

Figure 1. Cross-section through a single-cylinder steam engine showing the rotary and linear bearings.

employ a rolling action. In either case, it is important to provide enough lubrication to keep the metal bearing surfaces separated by a film of oil or grease.

The absence of direct metal-to-metal physical contact allows most bearings to operate satisfactorily for long periods with minimal wear. Metal shafts running in plastic bearings are an exception to this requirement and many can operate without any lubrication.

Ball, roller and needle bearings are all based on the use of rolling elements: balls in the first case, rollers in the other two. Plain bearings, on the other hand, rely on a sliding action. They tend to be less expensive than rolling-element bearings and, of course, can readily be made in the model-engineer's workshop. They do, however, result in higher levels of friction and, all other things being equal, will not last as long as rolling bearings. A bush is often used as a bearing; this is a cylindrical sleeve that can be inserted to provide a bearing surface for a shaft or just for a pin.

A bearing may be designed to carry loads along its axis of rotation or perpendicular to that axis, or a mixture of both. Rolling bearings that carry loads along the axis of rotation are referred to as 'thrust bearings'. Ball or roller bearings that carry loads perpendicular to the rotational axis are termed 'radially loaded bearings'; plain bearings carrying such loads are usually called 'journal bearings', or 'sleeve bearings'. Bearings are designated by the load they can carry, their speed range with that load, and their life expectancy under these conditions. Other factors include friction, start-up torque, ability to withstand impact or harsh environments, rigidity, size, cost and complexity.

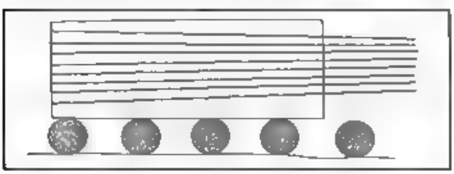

Figure 2. Probably the first application of bearings was in the rollers used to drag heavy stone blocks into place for ancient monuments.

It is clearly not possible in a book of this size to cover every single different type of bearing that can be made or purchased. The aim has been to cover all those types of bearing likely to be needed by model engineers, whether building a model or making or repairing a piece of full-size equipment in a home workshop.

Early bearings

Even before the Industrial Revolution, the provision of suitable bearings exercised

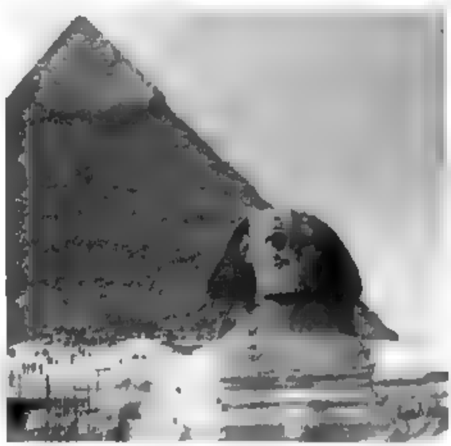

Figure 3. The building of the pyramids in Egypt some 4,000 years ago involved the use of roller bearings: logs to enable the large blocks of stone to be moved into position.

Figure 4. The earliest chariots used primitive bearings lubricated with animal fat. This Minoan artifact dates back some 4,000 years.

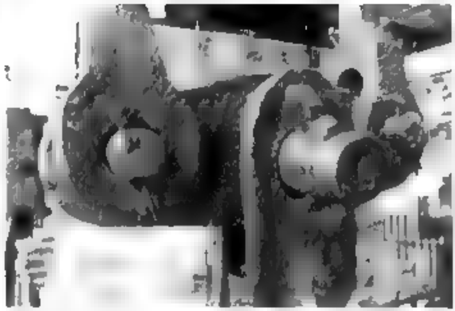

Figure 5. An example of the rudimentary bearings found on an early slow-revving static steam engine.

the ingenuity of human beings. It was the invention of the wheel, whose origins are lost in the mists of time, that drove people to search for suitable materials to make bearings for wagons and chariots. Bearings were also in demand for doors, boat rudders and rowlocks for the oars, as well as for water-lifting devices, like the Archimedes screw and the shadouf. Wagons required bearings that could sustain heavy loads while for chariots, the priority was speed. In both cases, low friction was important, as was long life. Unfortunately, bearing materials were limited to hardwoods and lubrication to the regular manual application of animal fat.

In the Middle Ages, clock-making drove the development of really low-friction bearings, though the rotational speeds of the moving parts in relation to the fixed parts was still extremely slow. It was the Industrial Revolution that further accentuated the need for improvements in bearing technology. Advances in metallurgy and the rapid development of increasingly powerful steam engines, initially operating at slow speeds in static locations but swiftly moving on to become the power source for locomotives, traction engines and ships, demanded significant advances in bearing design. And these improvements were on top of the increasing needs of stage-coaches which, though horse-drawn, stimulated the development of relatively high-speed, long-lasting, low-friction bearings.

Both the speeds which bearings had to withstand and the loads which they had to

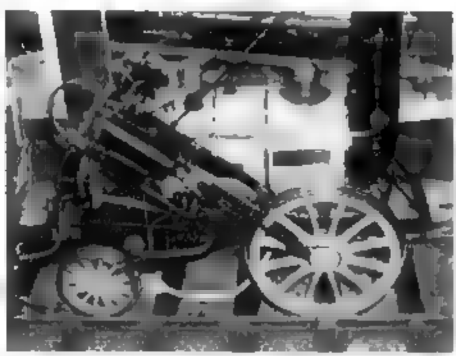

Figure 6. The arrival of a practical steam locomotive had a major impact on bearing design and construction.

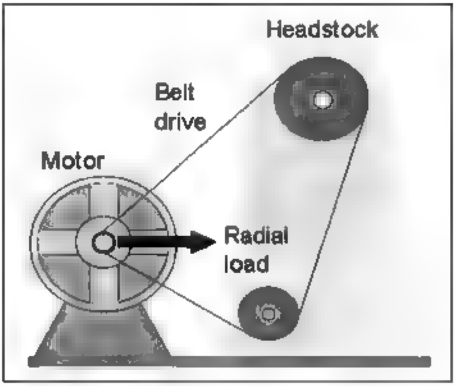

Figure 7. The radial load on a motor's output-end bearing.

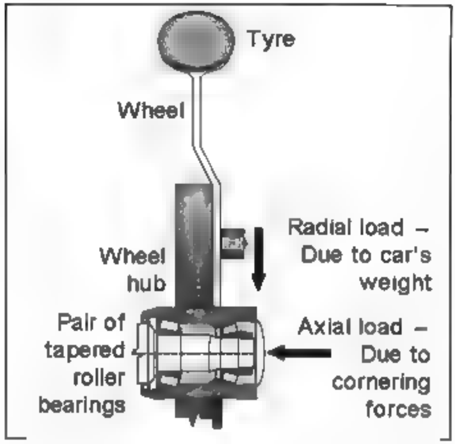

Figure 8. A car wheel bearing experiences both radial and axial loads.

carry grew dramatically from the mid-eighteenth century. At the same time, machine tools became an essential part of industrial life, demanding a degree of accuracy and precision undreamt of in the Middle Ages. Thus the nineteenth and twentieth centuries, with the expansion in the number of new materials available, saw the rapid development of a wide range of different types of bearings with enhanced performance. The improvements in production techniques resulted in large numbers of bearings that could be manufactured at prices affordable by model engineers.

Bearing loads

The most common load that any bearing must deal with is a radial load. This is shown in Figure 7, where an electric motor is driving a lathe headstock via a pair of pulleys. This type of load is commonplace in almost any motor-driven design. The second type of load is the axial load, which is considered in Figure 8. In this case there are still radial loads caused by the weight of the car, but in addition, axial forces occur when the car corners. While the design of most bearings enables them intrinsically to handle radial loads, additional axial loads are commonplace and often require special attention.

Finally, there is the linear bearing, where the loads tend to be relatively low and where the parts are in sliding rather than rotating contact. Figure 9 shows a locomotive crosshead and cylinder as a typical example of this. Four linear-bearing surfaces are shown. The two between the crosshead and the upper and lower slide bars involve some loads in the vertical plane, varying with the position of the connecting rod. Also shown are the lightly loaded piston-rod gland into the cylinder and the piston ring rubbing against the cylinder walls.

Bearing materials

Bearings can be divided into those that are home-made and those that can be pur-

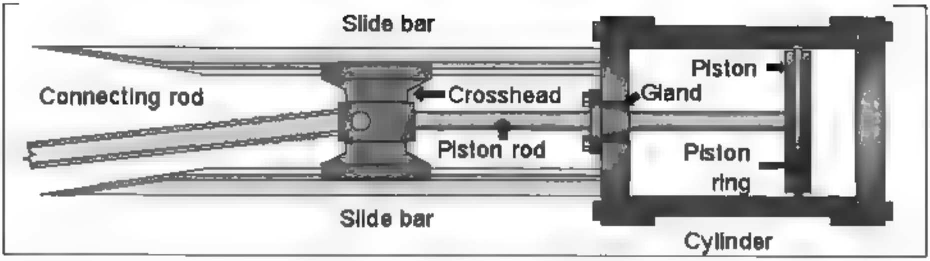

Figure 9. The cross head guides the piston rod in and out of the cylinder moving between the slide bars. It is fixed to the small end of the connecting rod.

chased. In the former category are many of the types of bearings used in engineering models. These include plain metal bearings comprising shafts or rods running in drilled or reamed holes as well as lapped sliding components, such as pistons, valves and cylinders. Purchased solutions include bought-in ball, roller and needle bearings as well as bushes, sintered bearings, packing materials and O-rings.

The choice of bearing materials normally has to be a compromise; some material pairings are particularly good, while others are less so. All the principal requirements of any bearing, seldom all found in a single material, are shown in Table 1 and care must be taken to use compatible pairs of materials.

Dissimilar metals are invariably required for shaft and bearing, aiming for the wear to be taken by the bearing rather than the shaft. With oscillating motion, it is often a moot point as to which component should take the wear.

White metals and bronzes are often used for plain bearings with steel shafts. Some metallic alloys are particularly well suited as bearing materials, because hard crystals occur in a matrix of softer metal, thus providing support for the shaft yet allowing a free flow of lubricant. The metals used need to have an affinity for lubricants since metal-to-metal contact generates heat and potentially scores or tears the metal, ruining the bearing. A small number of alloy constituents may act as a catalyst with some lubricants. For example, tin content in a bearing alloy can reduce the

Characteristic	Reason
Low friction coefficient	Reduces the power absorbed and heat generated
High thermal conductivity	Gets rid of heat generated by friction
Wear resistance	Long life
Corrosion resistance	Avoids deterioration of the bearing surfaces
Tough and ductile	To survive shock loadings
Fatigue resistance	Withstand vibrational loads
Strength and stiffness	To support loads
Permeability	Retains oil, absorbs dirt and avoids it causing damage

Table 1. The desirable characteristics when selecting bearing materials.

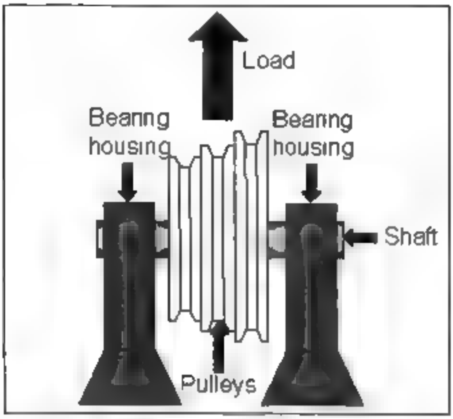

Figure 10. The correct position for bearings in relation to the load.

tendency of lubricating oil to sludge.

The finest alloy steels, often containing chromium and/or nickel, are employed in the manufacture of rolling bearings, both in making the balls and rollers as well as in fabricating the races. In the case of ceramic bearings, materials such as silicon nitride provide a range of performance benefits, including a high-speed capability and corrosion resistance.

Wood is one of the oldest of bearing materials and may still sometimes be employed for large slow-speed bearings. Hardwoods that readily absorb oil and grease make the best wooden bearings. Such bearings may also be made from oil-impregnated wood.

Plastics are increasingly being used to make bearings, particularly maintenance-free anti-corrosion ones that are based on lubricant-loaded polymers, such as nylon and PTFE. Even rubber, lubricated with water, can be used as a bearing material if some resilience is needed.

Bearing layout problems

When designing a model, there are several important factors that need to be considered from a bearing point of view. These mainly concern the positioning of the load in relation to the bearings.

Consider the case of a set of pulleys run-

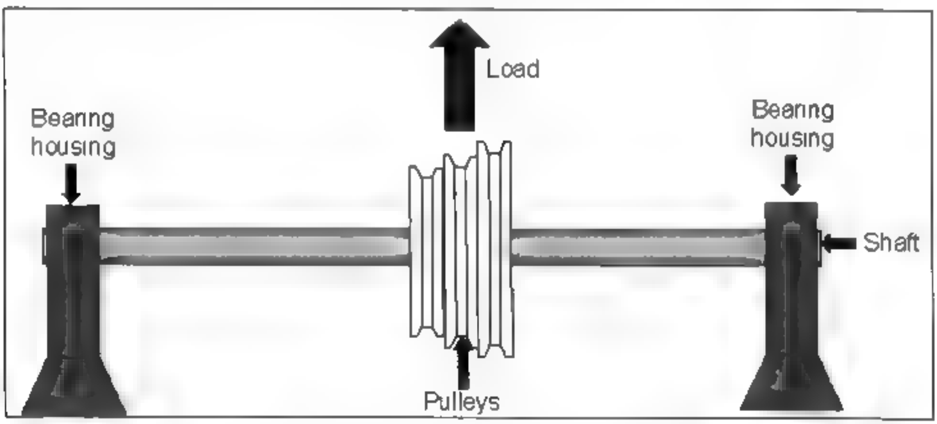

Figure 11. The shaft is likely to flex in the direction of the load and could even bend.

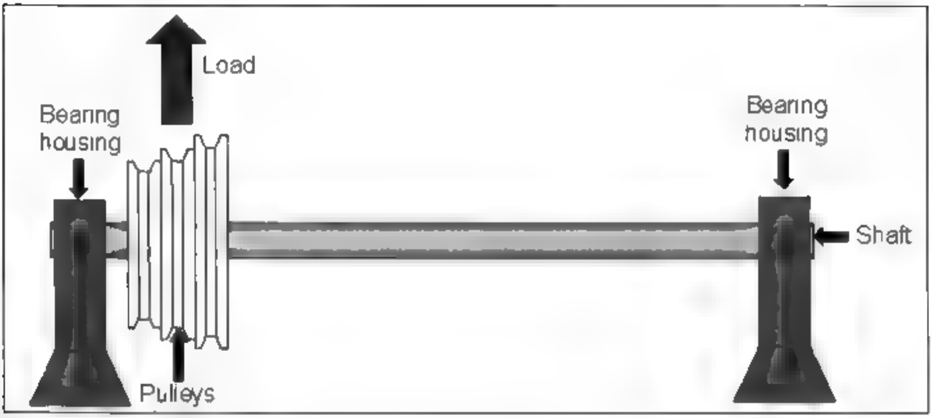

Figure 12. The shaft is less likely to flex if the load is placed close to one of the bearings, but this solution is still not as good as the one shown in Figure 10.

ning on a shaft. The ideal layout is to have the bearings as close as possible to the pulleys to which the load is applied. This is shown in Figure 10. On occasions, such ideal positioning of the bearings may not be possible. It may be necessary to use a longer shaft, as shown in Figure 11. In this case, the main problem is likely to be deflection of the shaft.

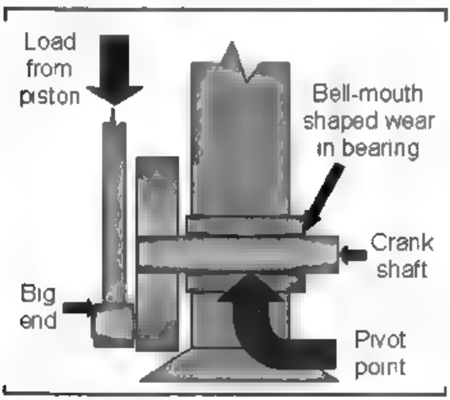

Figure 13. The cantilevered load on the crankshaft from the big end causes uneven wear on the main bearing.

Figure 12 shows an alternative positioning of the pulleys that places them close to at least one of the bearings.

The problem becomes far worse in the case of some engine layouts, such as single-cylinder internal-combustion engines, where it is tricky if not impossible to balance the rapidly

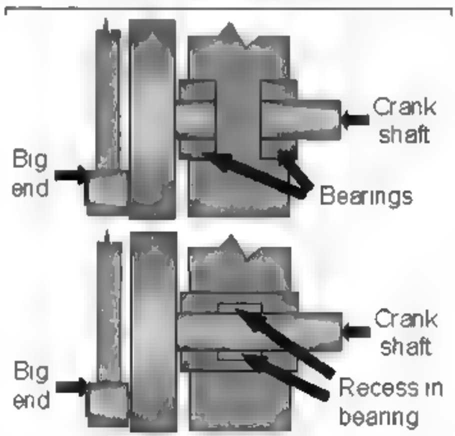

Figure 14. Two better designs of main bearing for a single-cylinder engine.

changing loads presented by the various rotating and reciprocating components. Often the bearing will act as a pivot for the load, causing uneven wear. Figure 13 illustrates the main bearing of a typical single-cylinder oscillating steam engine, showing the effective pivot point and how the bearing wears. The best way to overcome this problem is either to fit a pair of bearings or to provide a recess in the main bearing, which gives the same effect. This is shown in Figure 14.

A final issue is the question of alignment when two or more bearings are employed, as is usually the case. It is vital that care is taken to ensure that the bearings, when fitted, are parallel and in the same plane vertically and horizontally. This is essential to avoid unnecessary friction and bearing wear.

Bearing size

A question often asked is: 'How big should the bearings be?' Several factors need consideration. First, in the case of bearings fitted to a shaft, the shaft itself must be stiff enough to bear any loads placed on it. The length of the bearing can then be adjusted to take the necessary bearing load.

An example is the crankshaft of an internal-combustion engine, where getting adequate stiffness can prove difficult. Early full-size four-cylinder engines had just one main bearing at each end and this could cause problems due to lack of crankshaft stiffness. Improvements resulted from placing a third bearing in the middle of the crankshaft but modern engines have five bearings: one on either side of each connecting rod. Thus increasing the number of bearings reduces crankshaft stiffness requirements. In the case of a lathe mandrel, however, the over-riding factor may be the need to pass a bar of a certain diameter through the centre of the mandrel rather than its stiffness.

Second, in the case of plain bearings, it is important to consider lubrication needs as it is essential to avoid the oil film breaking down under excessive pressure. Speed of rotation is also a factor, but high speeds are better dealt with by using ball or roller bearings in place of plain ones. Although such bearings often take up more space than plain bearings, the use of needle bearings can result in a very compact solution.

Looking at some practical examples, a steam-engine big end will usually have a length equal to the diameter of the crank pin. But the bearings in electric motors used to provide continuous-belt drives for machine tools may well have bearings twice the length of the shaft diameter. If in doubt, always try to use a slightly larger rather than too small a bearing.

Imperial v. metric bearings

There are many model engineers who continue to use the imperial system when building models or working on full-size equipment, for a number of good reasons:

1. Many existing drawings for models use imperial units.

2. Many model engineers use imperial machine tools and measuring equipment.

3. The restoration of the majority of older full-size equipment demands the replacement of parts manufactured in imperial units

This does cause a dilemma since, although it is straightforward to manufacture bearings to imperial measurements, the cost of an imperial ball or roller bearing tends to be higher than its metric equivalent while availability

may be limited and is slowly reducing as the world becomes more metric-oriented.

About this book

The purpose of this book is to provide an overview of the various types of bearings that it is possible to make or use on models and also in some related full-size activities in the home workshop. The aim is to provide not only an understanding of their advantages and shortcomings, but also information about how specific types of bearing may be selected for the particular task in hand and how they may be fitted and lubricated.

The first chapter examines plain bearings, suggesting, from a wide range of materials, suitable pairings for shafts and bearings. These types of bearings are still commonplace and are found in many mechanical items, particularly where the loadings on them are relatively light. In addition, some types of plain bearing can be purchased off-the-shelf, particularly those made from ordinary or sintered metals and plastics.

The book then considers ball, roller and needle bearings that provide very low levels of friction and are widely available in a huge range of sizes and designs to suit even the most demanding applications. This is followed by an examination of the various types of linear bearings that deal with sliding or oscillating rather than rotating parts. Many, such as pistons moving in cylinders, may not be thought of as bearings, but the fact that there is relative motion and rubbing surfaces means that most of the normal factors necessary when choosing bearings need to be considered.

There are some special applications that demand bearings that have been designed for particular purposes and Chapter 4 looks at examples ranging from the high-speed bearings used in model gas turbines to the specific needs of clocks and watches.

After this, examination of the various different types of bearing, methods of providing seals and lubrication is then considered, followed by a chapter that looks at the factors that are important when choosing which type of bearing to use.

The final two chapters of the book give an overview of the many applications that require bearings when building models. They also consider some of the different full-size uses that many model engineers may encounter, such as clock-building and repairs to lathes and other machine tools.

The book finishes with a list of useful companies, their addresses and web sites, as well as a comprehensive index.

CHAPTER 1

Plain bearings

Introduction

The term 'plain bearing' is used to describe bearings for use with rotating parts that are not ball, roller or needle bearings. A plain bearing involves sliding contact between its two parts and, operating effectively in an ideal world, has a film of lubricant completely separating the shaft and bearing. However, since there may occasionally be a less than perfect film, metallic plain bearings need to use suitable materials to provide a satisfactory performance. Of course, the type of lubricant used is also important. Plain bearings are easily made in the average model-engineer's workshop with a minimum of tools and are suitable for the vast majority of applications.

Bearing materials

There is a wide choice of materials that may be used to make plain bearings and the only major limitation is the normal need to avoid using the same material to make the shaft and the bearing itself. As a result, bearings should be made of pairs of materials that are wear-resistant, minimise friction and are capable of carrying the required load. Clearly, both parts of any bearing should have a fine finish to minimise wear and friction, as well as to reduce the generation of any significant noise or vibration.

Wood

Wood may not the first choice of bearing material for the average model engineer but some models demand its use if they are to remain true to the prototype.

Undoubtedly, the first bearings ever pro-

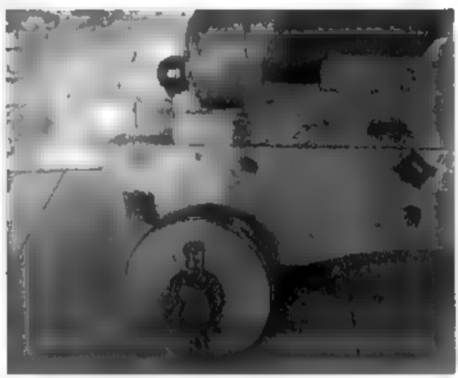

Figure 1. A wooden wheel bearing on an early cannon.

duced were made from wood and, despite the fact that most model engineers work in metal, there are some occasions when wood is the material of choice, particularly in certain classes of model. There are two key requirements for wooden bearings. The first is that they must be made from a hard-wearing wood to minimize abrasion of the bearing surfaces. The second is that adequate lubrication, which does not damage the material of the bearing, is essential. It is therefore fortunate that the need for wooden bearings is limited to areas such as modelling wagons, coaches and chariots, sailing ships, wooden agricultural machinery, water wheels, trebuchets and early cannon; undoubtedly this is the hobby of a minority of model engineers.

So which are the best types of wood to use? It must obviously be close-grained and hard, strong and tough, such as ash, beech, ebony, lignum vitae, mahogany, oak or teak. And for lubrication, animal fat was the primary source and is still a suitable lubricant. Roman chariots and Tudor carts all employed wooden bearings lubricated with animal fat. In the era of wind power, sailing ships used wooden bearing for their rudders, made from lignum vitae and early steam-powered ships continued to use lignum vitae as bearings for their propeller shafts.

For two reasons, it seems doubtful that long-lasting wooden bearings will be required in the vast majority of models. First they are unlikely to experience significant loadings and, second, they will probably not experience a prolonged working (as opposed to static) life. However, the situation may be very different for those model engineers who enjoy restoring antique full-size items. In this case, the use of the same wood as originally employed is recommended or, if this is not known, one of the tough, hard-grained varieties suggested above. And both for models and their larger brethren, lard provides an excellent lubricant for wooden bearings as well as being widely available.

Metal

It was the ability to fabricate accurate metal shafts and to drill precise holes in metal that led to the use of the earliest metal bearings; this skill was developed by blacksmiths a long time before the Industrial Revolution.

Prior to the invention of ball, roller and needle bearings as we know them today, making a metal bearing involved drilling a hole in a suitable piece of metal and fixing

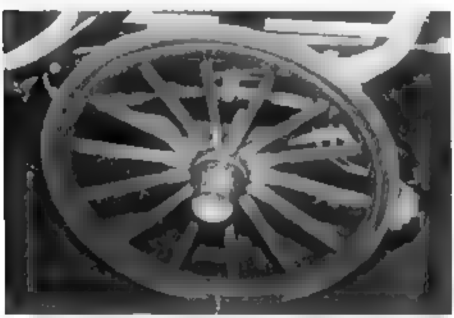

Figure 2. Coach wheels led the demand for continuous improvements in bearing technology.

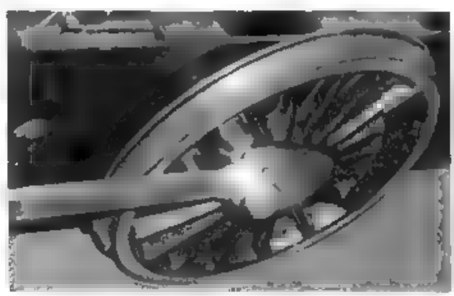

Figure 3. A plain metal bearing on the conrod of a 5" locomotive.

some form of metal shaft through it. However, because the two metals are rubbing against each other, it is important to provide a smooth finish to both surfaces, to reduce friction and to minimize wear, as well as some form of lubrication between the two surfaces. Furthermore, the two materials will need to be highly resistant to wear and able to carry the loads likely to be imposed on them. It is worth pointing out here that some models have to deal with remarkably high loads; consider the loading on the axle bearings under the seat of a human-carrying 3½" locomotive. In addition, consideration will have to be given to the operating environment of the bearing: dust, dirt, mud and water not being conducive to long bearing life. Furthermore, it was quickly discovered that bearings operate with fewer problems if they use dissimilar metals, so it is normally recommended not to use the same metal to make the two rubbing parts.

Aluminium

Pure aluminium is a very soft metal and quite unsuitable for use as a bearing material. However, an alloy of aluminium with small quantities of copper, iron, manganese, magnesium and silicon produces duralumin or dural,

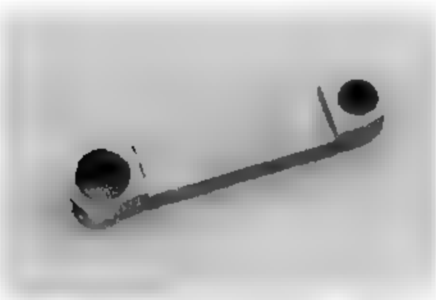

Figure 4. The conrod of a 4cc model aero-engine made from aluminium alloy. Note the lubrication hole in the big end.

probably the best known of the aluminium alloys. Dural is a strong and lightweight material that was and still is widely used in the aerospace industry. The best aluminium alloys have a similar strength to mild steel but only one third of their weight. Aluminium alloys are often used to make the connecting rods of small internal-combustion engines for model aircraft. Their bearing surfaces will require good lubrication to avoid scoring of the bearing surface and the rods of larger engines can beneficially be fitted with bronze bushes.

Babbitt metal or white metal

Babbitt metal, or white metal as it is often called, is named after the tin alloy invented in 1839 by Isaac Babbitt for use in steam engines. Although a tin-based alloy, it may also be alloyed with one or more of the following metals: copper, lead and antimony. It was later used in internal-combustion engines, when it was cast in place in the big ends of connecting rods and in lathe mandrel bearings, in both cases with excellent results. The hardened alloy is soft enough to be cut with a knife or sharp chisel and is readily damaged, making it appear unsuitable for a bearing surface. However, its structure consists of small hard crystals diffused in a matrix of softer metal. As the bearing wears the hard crystals are exposed and the erosion of the softer material enables the lubricant to flow between the high spots of the bearing surface. However, because Babbitt metal is so soft, it normally acts as a lining supported by another stronger metal.

The term 'run bearing' comes from this style of bearing, as lubrication failure will cause over-heating due to friction and lead to the white metal melting and running out of the bearing.

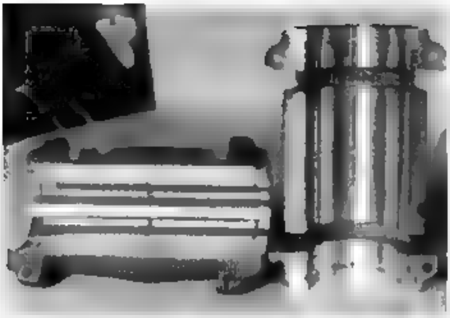

Figure 5. A pair of white-metal half-bearings, typical of those found in some older machine tools, that have been re-metalled on a base of cast iron. Photo courtesy Bearing Remetalling Service, Victoria, Australia.

Today, the crankshaft and big ends of full-size internal-combustion engines have bearings utilising a replaceable steel or bronze shell, keyed to the bearing caps. The inside of the steel shells are plated with a layer of bronze and in both types a thin layer of Babbitt metal provides the bearing surface. The bushes are normally retained in position in their housings by a parallel key or sometimes by a bolt through the housing with a locking nut. Figure 5 shows an example of a white metal bearing.

The major advantages of Babbitt bearings are that they that they provide beneficial damping and shock load capability. Their biggest snags are their need for careful running in and continuous lubrication, the skill needed to replace them, the fact that they can only support radial thrusts and, compared to rolling bearings, their relatively high coefficient of friction.

Brass

Brass, an alloy of copper and zinc, is often used for making plain bearings. It is a particularly popular material with clock-makers for use as clock plates since it takes an exceptionally fine polish. The plates themselves can be bored and counter-sunk to make bearings for the steel arbors that carry the clock pinions and gears, as well as providing small reservoirs for thin lubricating oil.

Bronze and phosphor bronze

Bronze is an alloy of copper and tin and is a suitable material for plain bearings, particularly when further alloyed with other metals such as aluminium, lead or manganese, but particularly with phosphorus. This last alloy, called phosphor bronze, has a finer structure than ordinary bronze and is both tougher and harder. It is probably the most popular plain-bearing material for steel shafts. It is notewor-

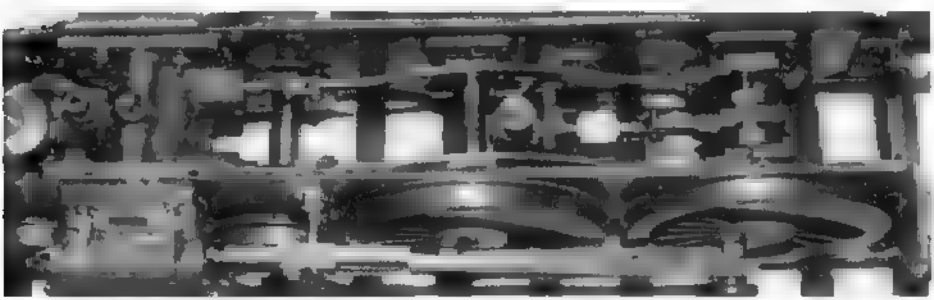

Figure 6. The chassis of a locomotive carries a plethora of different types of bearing.

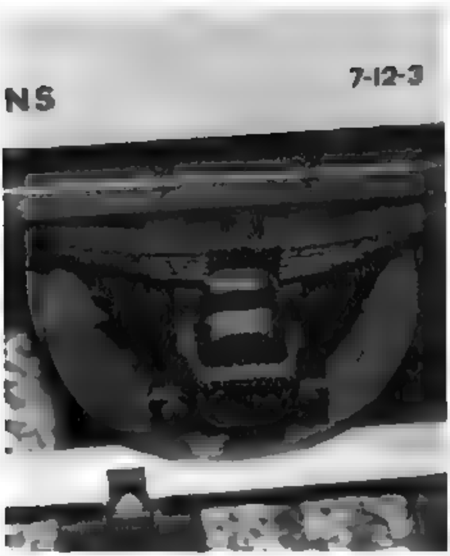

Figure 7. A typical cast-iron axle block in which the steel wagon axle runs.

thy that continuous-cast phosphor bronze is considerably easier to machine than drawn phosphor bronze. Other additives to bronze include lead, which improves machineability and the capacity to continue to perform under conditions of poor lubrication at the expense of toughness. However the addition of some nickel does help to improve strength and reduce any tendency to brittleness. While not usually recommended, it is possible to use a pair of different bronze alloys, such as gunmetal and phosphor bronze, to make both parts of a bearing pair.

Cast iron

Because of its in-built graphite content, cast iron is an excellent bearing material. In use with a steel shaft, the surface of the cast iron gains a tough glazed surface that is very wear-resistant. An additional advantage is

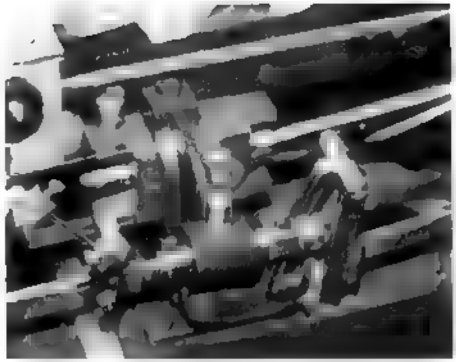

Figure 8. Rods, levers and linkages all need some form of bearing.

that cast-iron bearings will continue to operate satisfactorily even in conditions of poor lubrication, though this is no excuse for failing to provide an adequate supply. A relatively unique property of the material is its ability to be used in conjunction with itself. Thus, the cast-iron slides of machine tools may rub against cast-iron mountings or gib strips of the same material.

Gunmetal

One of the best materials for use as a bearing material is gunmetal. Originally the name given to a group of bronzes used to make cannons, gunmetal casts well, is quite strong and is corrosion-resistant. 'Bearing bronze' is used to describe any bronze that is suitable for use as a bearing material. It is particularly applied to gunmetal incorporating significant amounts of lead for friction reduction. Gunmetal with some 30% lead is superior to Babbitt metal as a bearing material and is sometimes called 'plastic bronze'.

Steel

The vast majority of axles, spindles, shafts

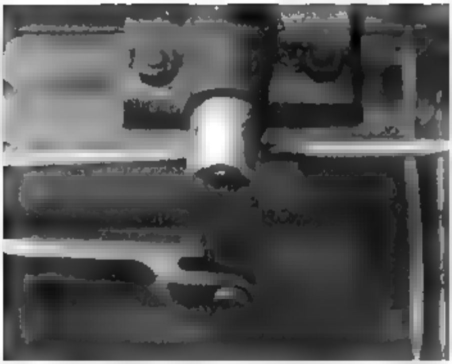

Figure 9. The pushrod connected to a rotating shaft is a classic application for a steel running in steel bearing.

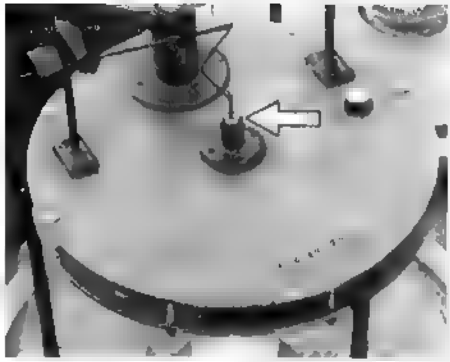

Figure 10. A PTFE bearing on a hot-air engine, marked with an arrow.

and pivots are made from steel, a material that is hard-wearing and able to withstand high working stresses. Both mild steel and many alloy steels are suitable; the chemical composition of the steel provides a range of benefits, including improved corrosion resistance, better machineability and enhanced strength.

While mild steel may be used, silver steel or alloy steel containing elements such as chromium, vanadium, tungsten or cobalt will prove to be much better-wearing. Steel can, of course, be tempered to increase hardness and wear resistance but, for the model engineer, this brings with it a new set of problems. Obtaining an accurate finish may require grinding and/or lapping of the hardened shaft. Fortunately, unhardened steel will run in bearings made from a range of materials, such as lead- and tin-based alloys, cast iron, phosphor bronze, gunmetal and brass, making these materials popular for lightly loaded plain bearings that are inexpensive to make.

As a bearing material, it is only feasible to run a steel shaft in a steel bearing if both items are hardened and provided with a fine finish, in which case a long-lasting bearing will result, but only if adequate lubrication is available. However, it is still preferable to use a bronze bush in a steel bearing housing. When running steel shafts in phosphor-bronze bearings, hardening is advisable but, in white metal bearings, such hardening is unnecessary. Stainless steel is a popular choice for shafts exposed to water or steam, where rust is likely to be a problem, though machining stainless steel brings difficulties of its own. Rustless steel may prove to be a better choice as it is easier to work and still has a useful degree of corrosion resistance.

Plastics

The use of plastics to make bearings offers a number of advantages. First, they can provide very low levels of friction and low wear rates without any lubrication. Second, there is no risk of corrosion to the bearing when exposed to what are hostile environments for ferrous metals, such as fresh or sea water. However, plastics are only suitable for relatively lightly loaded bearings.

PTFE, also known as Teflon and Viton, is renowned for its remarkably low co-efficient of friction (0.02–0.1) making an ideal material for any relatively lightly-loaded bearing. It is resistant to almost all chemicals and can withstand relatively high temperatures. A word of warning here, however. When drilling PTFE, it starts to decompose at 270°C, producing poisonous fumes. So, avoid any over-heating of the material when working it and do not smoke since the PTFE dust could be drawn into a cigarette or pipe and poison the smoker.

Other useful bearing materials include nylon and acetal. Nylon is easily drilled and may be used to provide propeller-shaft bearings on model boats. Both MoS_2 filled cast nylon 6 and Nylatron GS incorporate molybdenum disulphide to reduce friction. Teflon-filled acetal provides excellent lubrication properties when used as a bearing material with steel. Delrin, a Du Pont proprietary form of acetal, has lower water absorption and better abrasion resistance than nylon and is easier to machine. Recently developed new polymers, such as Iglidur, are being used to replacing traditional graphite or carbon sleeve bearings and bushes.

Plastic bearings are well worth considering for any application that does not involve heavy stresses, whether using proprietary purchased bearings or ones made in the workshop, the latter being easier to make than metal bearings. And, of course, the lack of a need to provide regular lubrication is a major advantage.

Making plain bearings

While it is possible to buy a wide range of ready-made plain bearings and bushes to fit in suitable housings, the majority of model engineers will want to custom-make plain bearings in their workshops.

There are always two considerations when making a bearing. The first is the shaft size and, with steel normally being chosen, this is generally determined by the need for adequate strength. The second factor is the choice of bearing material and here an examination of the desirable characteristics usually reduces the choice. So it is useful to begin by asking a number of questions:

1. Is minimum friction important?
2. Will the bearing get a lot of use and need to resist wear?
3. How heavily is the bearing likely to be loaded?
4. Does the bearing need to be fatigue-resistant?
5. Will a lot of heat need to be conducted away from the bearing?
6. Is corrosion of the bearing likely?
7. How fast will the bearing turn?
8. Is a material that is easy to machine and finish important?
9. How will the bearing be lubricated?

The answers to these questions will influence the choice of bearing materials and may lead to an almost automatic choice of material. Otherwise it will be logical to choose a favourite material, such as phosphor bronze or cast iron, the one specified on a plan, the material used in the prototype or the same material as the original bearing if a replacement is being made.

The application will often make the bearing choice clear. A model internal-combustion engine will have relatively fast-turning and highly loaded main, big- and small-end bearings compared with a miniature steam engine. At the other extreme, the bearings in a control linkage tend to be lightly loaded and

experience only limited movement.

Having selected the material and knowing the size of the shaft, the question then arises of how much clearance should the bearing have, or what size hole. Would that a simple figure could be quoted. However, a well-fitting bearing will only have a minimal clearance to avoid vibration when the shaft is turning. The clearance will depend very much on the bearing material. 0.025mm (0.001") is a good figure for a model internal-combustion engine while 0.05–0.07mm (0.002–0.003") clearance is a practical starting point for less highly stressed applications. A very close fit is possible with a cast-iron bearing, the in-built graphite providing an reasonable degree of lubrication. A larger clearance would be necessary with brass or phosphor bronze. Next, there is the question of load and running speed, both of which can generate frictional heat that can break down an oil film and damage the bearing surface. Thus a heavily loaded or a fast-running bearing will require greater clearance than a slow-running, lightly loaded one.

Ready-made bushes and bearings are sold with many different inside and outside diameters and are manufactured from a number of different materials. They are usually push fit and should be 0.05–0.07mm (0.002–0.003") oversize for their housing. A good alternative to a push fit is to use a retaining adhesive such as Loctite 601.

Single-piece bearings

When making a single-piece as opposed to a split bearing, it should be drilled and preferably reamed to fit its polished shaft, though the shaft itself may be turned to fit the bearing. It is also essential that the hole is drilled in exactly the right place, demanding accurate marking out, and also that the hole is drilled at right angles (or the correct angle) to the surface of the material, in both planes. Any inaccuracies are likely to lead to early bearing failure.

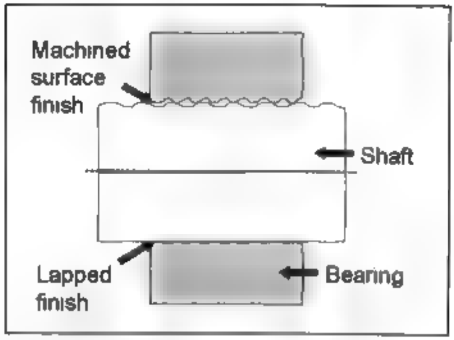

Figure 11. A magnified view of a shaft in a bearing showing the difference between a machined and a lapped finish.

While this type of hand fitting is fine for the model-maker, it has all but disappeared from the industrial world, where the priorities lie with rapid de-skilled assembly of parts that are often produced in separate factories, frequently located in different countries. Thus, most model engineers develop a skill for fitting bearings with the optimum clearance and with experience can identify a correctly and closely fitting bearing by feel alone.

Finally the question arises of how the bearing will be lubricated. At one extreme, a plastic bearing may require no lubrication. At the other extreme, an oiling or greasing point may be needed, possibly with oilways cut into the bearing material. The subject of lubrication is dealt with in more detail in Chapter 5.

Bearing finish

The standard of finish given to a plain bearing can have a dramatic impact on its effective

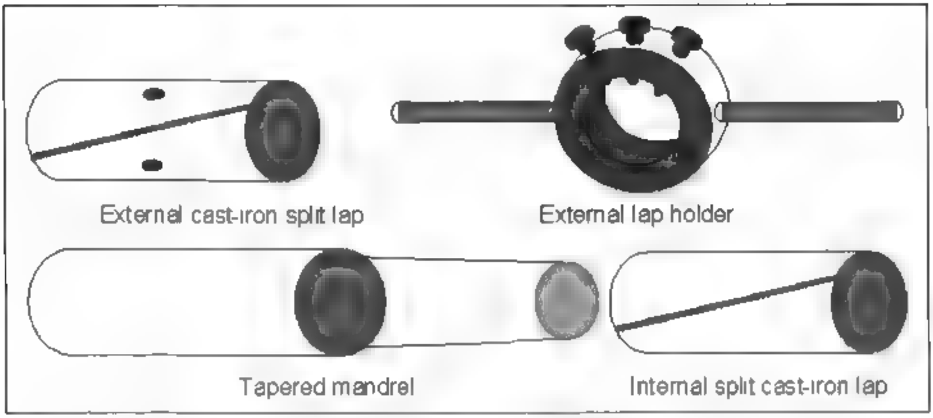

Figure 12. Internal and external laps for lapping shafts and bearings. Laps may also be made from aluminium, brass or copper.

working life and also affect the level of noise it generates. Any shaft or bearing needs to be both parallel and circular. However, if it is finished on a lathe it will not have a flat surface but rather a series of ridges and valleys, thus limiting the contact area between the two parts as the top half of Figure 11 shows. This can lead to a breakdown of the oil film between the limited number of contact points, thus producing excessive heat and wear, leading to a poor fit of what appeared initially to be a perfect fit.

For a better solution, the shaft should ideally be ground and the bearing reamed to size or finished with a broach. A reamer will certainly produce a satisfactory bearing surface for a linkage or other slowly rotating part but is far from ideal for a bearing for a continuously turning shaft. This approach will, after running in, wear away the odd traces of ridges and valleys and result in a well-fitting bearing as little metal will have been worn away. Be aware, however, that new reamers may well make holes that are marginally over the specified diameter.

Lapping bearings

The best results of all come from lapping the surfaces of the shaft and the bearing using a series of increasingly fine abrasives. A relatively soft material is used as a lap and is 'charged' with an abrasive such as aluminium oxide; this is ideal for use on non-ferrous metals and unhardened steel. Suspended in thick oil or grease, these abrasive mixtures are sold as grinding pastes. The lap is then used to cut the bearing surface. The abrasive embeds within the softer material of the lap, which holds it and permits it to cut the harder bearing or shaft material. If a fine abrasive is employed, this will produce a well polished surface. Expect to remove 0.025–0.05mm (0.001–0.002") of material during the lapping process. The material of the lap needs to suit the metal being lapped. Laps are commonly made from cast iron, brass, copper or aluminium; all are suitable for use on steel. Brass and copper can be used on cast iron

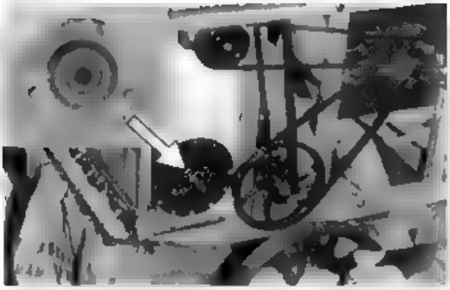

Figure 13. A bronze bush in an end-plate of the type fitted to a threshing machine.

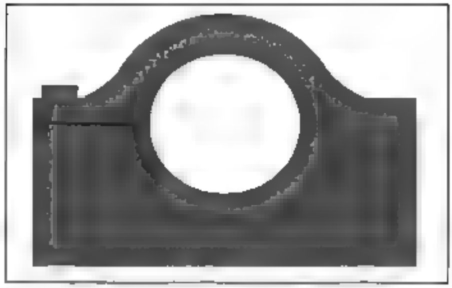

Figure 14. A simple bearing split only on one side, with a bolt on the open side to close the bearing on that side.

while copper and aluminium may be used on brass or bronze. It is essential that the abrasive is not absorbed into the item being lapped and is cleaned off at the end of the lapping process.

Model engineers can chose from a wide range of lapping compounds. Lapping paste (or valve-grinding paste), usually comprising silicon carbide mixed with lithium-based grease, is widely available in five increasingly course grades: fine 220 grit, standard 180 grit, medium 120 grit, coarse 80 grit and extra coarse 30/60 grit. The choice of grade depends on the task in hand: rough, general or finish lapping. The fine grade provides a polished surface. Normally only the two finest grades should be necessary. If lapping powder is used, it may be mixed with lapping oil to form a paste or applied to the lap in powdered form and the excess wiped off.

Powders range from diamond, the most expensive but able to give the best finish, through emery to crocus, the finest grade. A metal polish may also be used to give a final polish. Different lapping compounds are available for use with hard metals (cast iron, hard bronze, steel and stainless steel) and soft ones (aluminium, Babbitt metal, brass and bronze) It is essential to clean off any paste or powder after lapping and this is readily done with paraffin.

It is important not to attempt to lap a shaft directly into its bearing. First, the rate of wear of the harder shaft is likely to be lower than that of the softer bearing. Second, if the harder part is the less accurately finished part, then the other will take up the inaccurate shape.

Bushes

A bush is used where the material through which a shaft runs is unsuitable. As an example, the chassis plates of most locomotives and traction engines are made from steel and, if a steel shaft runs through these plates, a bush of a suitable material is required

These items are easily turned up from any suitable material, such as one of the bronzes, in the same way as any other plain bearing. The vast majority of model engineers will make their own; alternatively, ready-made bushes may be purchased. In both cases, it is a straightforward task to press them into place in a suitably sized hole in the housing. For modelling applications, the bush should be some 0.05mm (0.002") over-size and carefully pressed into place with uniform pressure

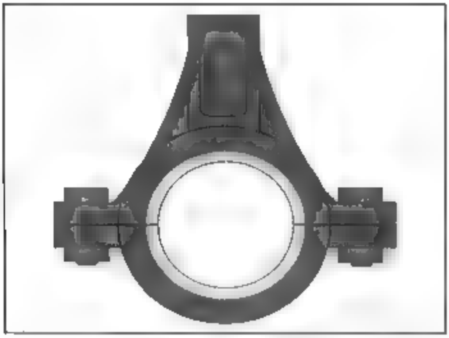

Figure 15. A typical big-end split bearing; the halves bolted together.

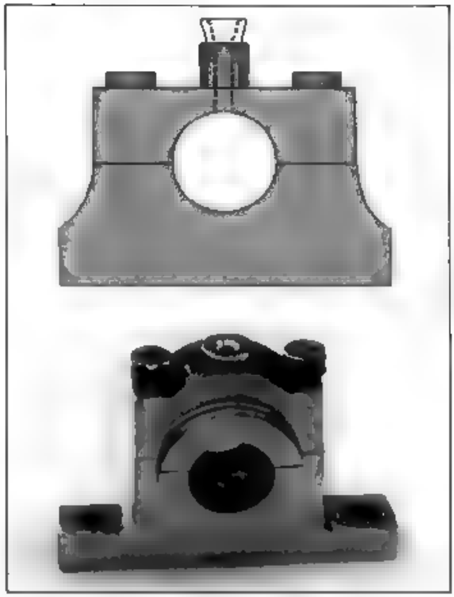

Figure 17. Top, a design for a brass main bearing with lubrication hole; bottom, a typical example of one.

to the end of the bush. Alternatively a suitable adhesive may be employed.

Split bearings

The simplest form of split bearing involves cutting through the metal on one side and perhaps just into the other side, then using a bolt and shims to enable any slack in the bearing to be taken up. This is shown in Figure 14. For some applications, and the crankshaft for a multi-cylinder engine springs to mind, a bearing split completely into two halves considerably simplifies assembly.

It may well be that the bearing material is the same as for a single-piece bearing and normal practice is to cut the bearing material in half along the dividing line using a slitting saw and then to soft-solder the two halves together before forming a suitably sized bearing hole. Drill the hole slightly under-size and then ream to size. The solder is then melted and the bearing halves bolted together. Sometimes soldering can be avoided if the bearing halves can be bolted together before

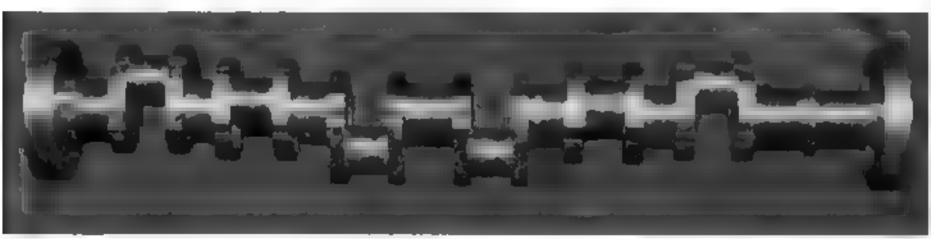

Figure 16. A real challenge; a six-cylinder engine crankshaft requiring 13 split bearings.

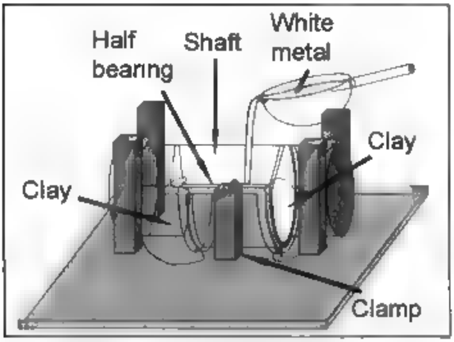

Figure 18. Pouring white metal into a half bearing. Both the bearing and the shell must be firmly secured in place with clamps and not just rely on the clay to hold them.

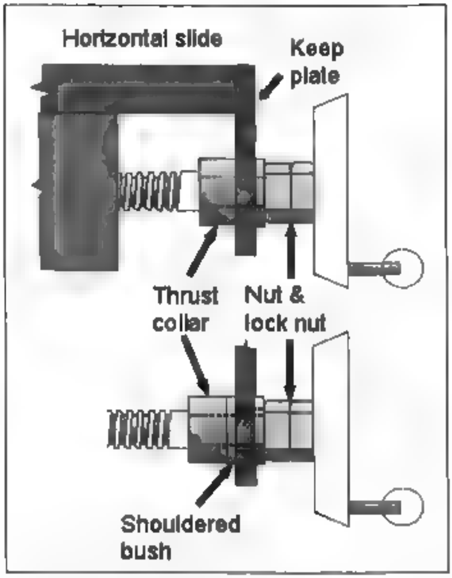

Figure 19. A thrust collar (top) and a thrust collar with a shouldered bush (bottom) fitted to the cross-slide of a lathe.

drilling takes place. A split bearing needs to be carefully fitted and, if it is too tight, shims may be used to correct for over-tightness and allow any subsequent wear to be taken up by removing shims. However, it is important to check that the tightness is not the result of the bearing being too narrow and requiring enlarging.

Re-metalling bearings

Replacing early white-metal bearings involves a casting and scraping process that is not too difficult since Babbitt metal has a relatively low melting point, typically less than 300°C. As an example of the procedure on a split bearing, start by removing any old Babbitt metal, using a gas flame and getting it immaculately clean. Roughen the inner surfaces using a file and tin the surfaces, using plumber's solder and flux, by heating the bearing halves until the solder melts. Then pre-assemble half the bearing as a loose fit around the shaft in roughly its correct final position. Next pack the ends of the bearing with clay and pre-heat the assembly. The molten white metal is then carefully poured into the space surrounding the shaft up as far as the housing split. The inner face of the bearing housing may be pre-drilled to provide a key for the bearing metal as it is cast into place.

The half-bearing is then removed and the white metal trimmed back to the mid-point of the split housing. The half bearing and its cap are again assembled around the shaft, using a steel shim to protect the lower bearing and to space the cap away from the shaft. After re-sealing the ends with clay, more white metal is poured in to fill the cap of the housing through the lubrication hole in its top.

The two halves of the bearing are again split at the shim, the oil hole cleaned of white metal and any oil ways cut in the new bearing surface. After smearing the shaft with

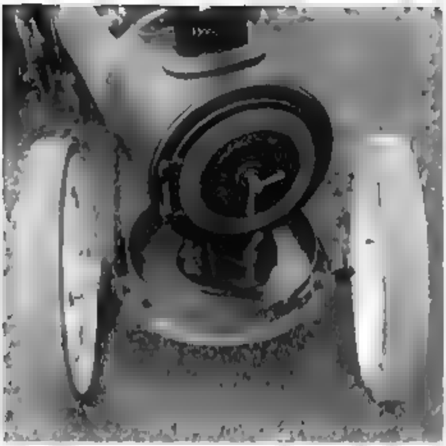

Figure 20. Thrust collars are needed both for the steering end for the front-wheel bearings

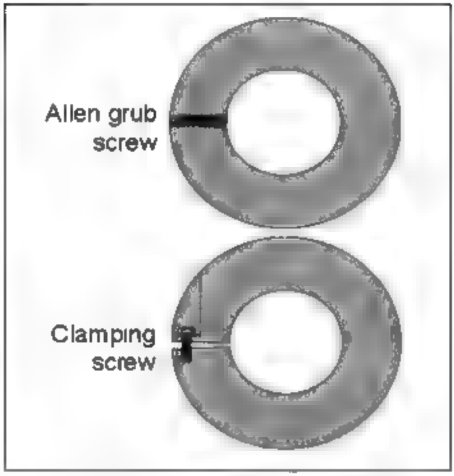

Figure 21. Two different methods of locking a thrust collar to its associated shaft: top using a grub screw and bottom a clamping screw.

engineer's blue, the bearing is fitted to it and rotated. On disassembly the high spots can be scraped down and the process repeated until a good fit is achieved. The bearing is finally cleaned, lubricated and may be shimmed so that the shaft is held firmly without binding.

The assembly then needs to be run-in at low speeds and light loads until the hard bearing surface is exposed. After a final adjustment of any shimming, a very reliable and high-load-capability bearing results.

Remember the dangers of molten metal as well as the fact that most Babbitt metal has a significant lead content. Figure 18 shows the pouring process and Figure 5 on Page 14 illustrates the completed results.

Thrust collars

While plain bearings may be excellent for rotating parts, they are not normally able to resist axial loads. Thus there is often a requirement for thrust collars when such loads are present as, for example, on a ship or aircraft propeller shaft and on lathe cross-slides, as shown in Figure 19.

Plain metal thrust collars, as with bearings, can be made from the same range of metals and plastics and may or may not push against a shouldered bush rather than just a metal plate. Again, it is important to employ dissimilar metals for the thrust collar and whatever it pushes against.

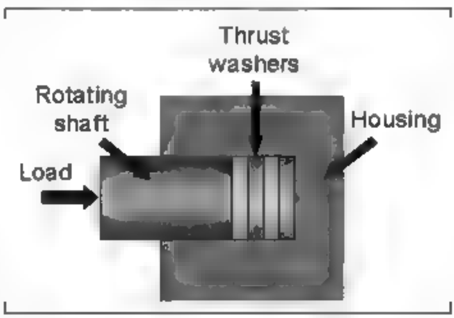

Figure 22. The use of thrust washers to support an end load on a rotating shaft.

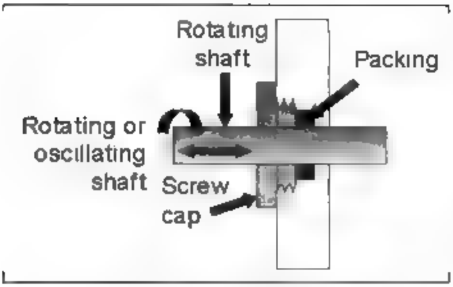

Figure 23. A stuffing box with packing compressed behind a screw-in cap.

The thrust collar needs to be anchored to the rotating shaft, and two popular methods are shown in Figure 21. The first involves a small grub screw that presses against the shaft, preferably where a small flat has been filed or a dimple drilled. The second employs a clamping screw to close the gap in a split collar. Lower friction, longer-lasting methods of supporting axial loads are covered in the next chapter, which deals with the use of ball and roller bearings.

It is also possible to make a plain thrust bearing to carry axial loads and one possible solution is shown in Figure 22. Here the end thrust of the shaft is taken by a series of thrust washers comprising alternate bronze and hardened steel discs. If four discs are employed, seizure of a single pair due to inadequate lubrication will not stop the shaft from continuing to turn. Of course, in this case, the steel shaft is turning in a cast-iron housing.

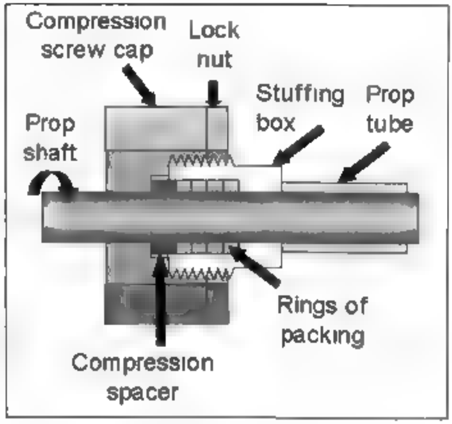

Figure 25. The layout of a typical marine prop-shaft stuffing box; bearings not shown.

Glands and stuffing boxes

It can be argued that neither glands nor stuffing boxes are bearings and, indeed, they may

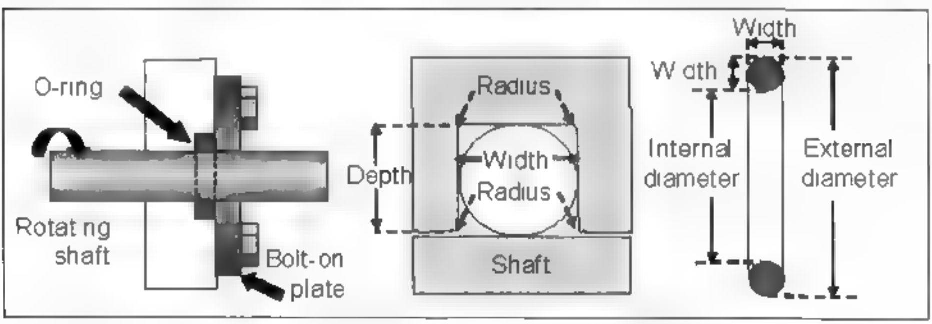

Figure 24. A gland fitted with an O-ring seal showing the design of the groove and the way an O-ring is dimensioned.

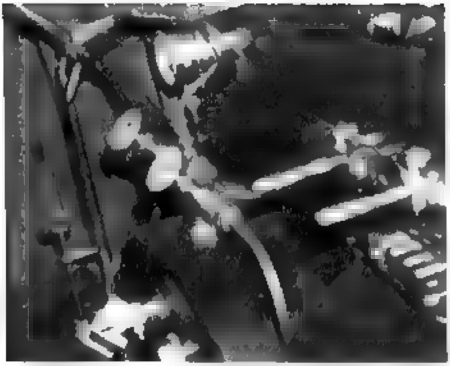

Figure 26. Both manually operated rotary valves are fitted with stuffing boxes.

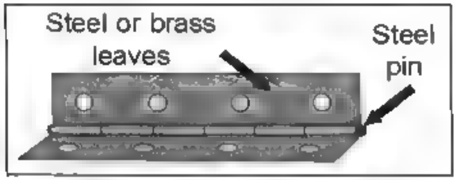

Figure 27. Construction of a typical hinge showing the pin/leaf bearing interface.

or may not provide support for a shaft rotating through the gland. However, glands are needed to prevent steam, oil or water leakage on many rotating and oscillating shafts. An example is found in any (non-ceramic washer) domestic tap, where the gland is usually packed with string soaked in tallow or grease. The gland nut allows the packing material to be compressed to form a watertight seal and prevent water leaking up the shaft when the tap is turned on and off.

A gland on a rotating or oscillating shaft may be packed in a similar way to a household tap, to provide a seal and allow continuous movement. Such seals are found around the piston rod of double-acting steam engines as well as around the valve-operating rods. Likewise, propeller shafts and rudder or hydroplane shafts are fitted with glands.

A stuffing box is a small chamber containing the packing that is compressed to form a seal and to prevent leakage around a rotating or oscillating shaft. The packing, in the case of most engineering models, is graphited-grease yarn or a synthetic material, such as PTFE thread.

It is not good practice to wind the packing as one continuous length around the shaft as it will not provide an adequate seal. It should be installed as a number of stacked rings, each cut to a length that just surrounds the shaft with its ends touching.

O-rings

A particular type of gland is the one where an O-ring is used in place of packing and this type of solution is becoming increasingly popular. O-rings are moulded in one-piece with a circular cross-section and are made from synthetic rubber. They are used to prevent fluid movement between mechanical parts by maintaining contact with the inner shaft and the outer walls of the gland enclosing the ring. The resilient rubber provides a seal but, when pressure is applied, the fluid forces compress and deform the O-ring across the groove and enhance the seal against leakage. O-rings are suitable for use in either axial or radial glands.

The choice of O-ring material will depend on the fluid to be sealed: steam, oil or water. O-rings may be made from nitrile rubber, silicon rubber or Viton, the majority of which are steam-grade. The size of an O-ring is defined by its inner and outer diameters (the combination of the two identify the thickness of the ring), its hardness and the material from which it is made.

The width of the groove in which the O-ring

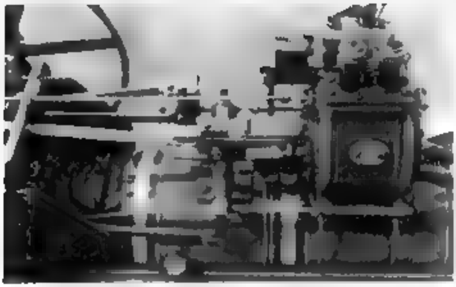

Figure 28. The multiplicity of control rods and linkages fitted on top of the boiler of a traction engine.

fits should be one-and-a-half times the width of the ring while its depth should be some 80% of the ring's width.

The use of harder O-rings may result in higher friction and a tendency for the seal to leak at low pressure. The surface finish of the groove seriously affects the performance of the seal and every effort should be made to ensure a smooth finish to avoid damaging the surface of the O-ring. The moving shaft should be polished to maximise the life of the O-ring. It is preferable to stretch any O-ring slightly during assembly so that it sits securely in place. This can be done by selecting an O-ring with an internal diameter 2½% smaller than the shaft on which it sits.

Hinges and pivots

Small hinges, when needed, are best purchased ready-made or fabricated from folded brass sheet with a steel or stainless-steel pin. For more heavily-loaded hinges, steel may be used in place of brass. However, in both cases, occasional lubrication is needed to avoid stiffness and squeakiness.

Figure 29. A barrel organ like this one requires both pivots and hinges.

Almost every model will require a number of linkages that will inevitably include one or more pivot points. Occasionally, these linkages will be operated by rotating a small handle (steam-engine reversing gear and locomotive brakes are examples) but mainly the mechanisms are push-pull and require bearings able to deal with rotation over an angle of, typically, 90°. A brass or bronze fitting with a steel pin is often a simple solution that only requires a very rare drop of oil. Even a steel fitting with a steel pin can be acceptable.

Where very precise transmission of movement is required, completely slop-free bearings are essential and their number should be minimised along the length of the connection.

CHAPTER 2

Ball & roller bearings

Introduction

It is difficult to be certain when ball and roller bearings were invented. The ancient Egyptians are known to have used logs as roller bearings when moving the large blocks of stone to build the pyramids. The same is almost certainly true of the people who built Stonehenge. The Italian Leonardo da Vinci has left a clear illustration of a caged ball bearing much as we think of it today, despite the fact that its construction was based on the use of wood. The caged roller bearing as we currently know it was invented by John Harrison in the mid-eighteenth century during his efforts to produce a chronometer sufficiently accurate to measure longitude on board a ship. However, in 1791, English inventor Philip Vaughn obtained the first patent for a practical ball bearing for use on the axles of carriages.

What is clear is that both ball and roller bearings offer considerably lower levels of friction and also require less lubrication than plain bearings; both are important benefits.

There are five basic types of rolling bearing available on the market. The two

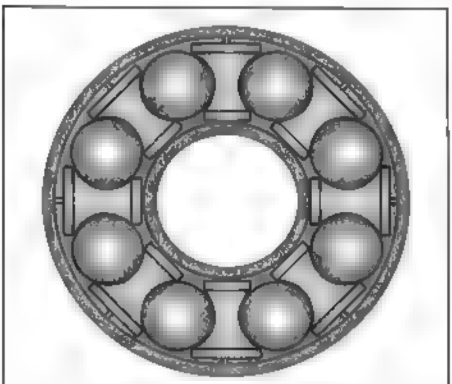

Figure 1. Leonardo's innovative design for a ball race, drawn some 500 years ago, would have been made from hardwood.

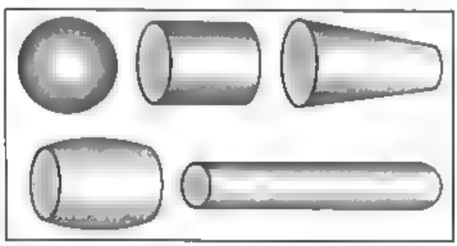

Figure 2. The five different types of ball and rolling elements. top – ball, cylindrical and tapered; bottom – spherical and needle.

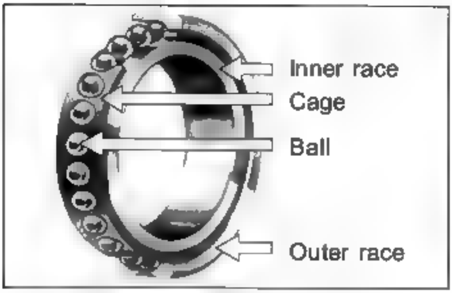

Figure 3. *A sectioned single-row ball bearing, showing the component parts. Photo courtesy the Timken Company.*

main types are ball and roller bearings and the latter encompasses four different types of roller: cylindrical, tapered, spherical and needle. Each is named after the shape of its rolling part, shown in *Figure 2*. Both the size and, in the case of roller bearings the length to diameter ratio, vary.

Ball bearings offer an economically priced solution for bearings that are small and relatively lightly loaded, while roller bearings better suit applications that require large bearings that are heavily loaded. They also perform better under conditions of shock or impact loadings. Thrust ball bearings deal well with axial loads but, for high loads, angular-contact or deep-groove ball bearings may provide a better solution. Bearing cages may be made from steel, brass or reinforced plastics. Bearings supplied with seals can be pre-lubricated and operate for lengthy periods without any maintenance. Speed of operation, loading, environmental conditions and lubrication will all affect the choice of bearing. It is worth remembering that that the maximum rated speed of any rolling bearing is generally inversely proportional to its diameter.

In cases where rolling bearings are operated within their design parameters,

Figure 4. *A range of different types of ball bearings. Photo courtesy the Timken Company.*

adequately lubricated and protected from the ingress of dirt, failure is normally caused by fatigue in the contact area between the balls or rollers and the races as the bearing comes to the end of its design life, defined as the number of revs at a given speed and loading.

Ball bearings

A ball bearing, occasionally referred to as a 'ball race', is a friction-reducing bearing and basically consists of two concentric steel ring-shaped tracks containing freely revolving, hardened steel (or more recently ceramic) balls. The term 'ball bearing' is also used to describe each of the hardened balls. The outer ring is normally held in a suitable aperture in the static part of the mechanism while the rotating shaft fits within the inner ring and is able to turn freely and with little friction. A metal cage prevents the balls from rubbing against each other. The purpose of the cage is to hold and separate the rolling elements (balls) of the bearing.

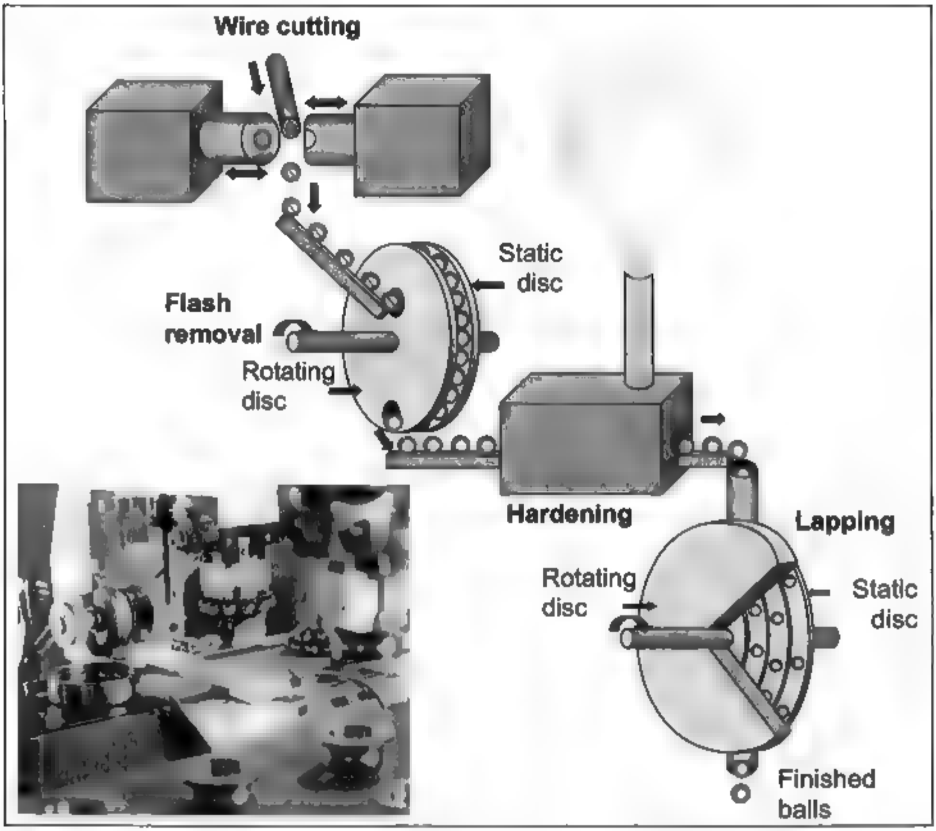

Figure 5. *Diagramatic view of the manufacture of balls. Inset, automated assembly of bearings. Photo courtesy Schaeffler UK.*

Manufacture
Manufacturing ball bearings involves using very high-quality materials, mainly carbon/chromium or martensitic stainless steel. A machine with two hemispherical plates cuts metal wire, made from steel of roughly the same diameter as the ball bearings, to form a metal ball. The balls then go to another machine with a pair of grooved plates to remove any flash and ensure roundness and a uniform size.

After hardening, the balls then make a pass through a similar machine, which adds a lubricant and abrasive mix to grind the balls to a precise size. Finally the ball bearings are polished to reduce friction.

The balls then have to pass a stringent quality check before they are fitted into ball races with a cage to prevent the balls rubbing against each other. There is a range of popular ball-race designs, each with its own advantages and

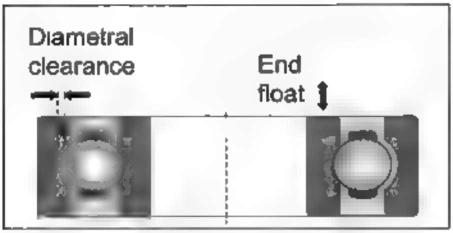

Figure 6. *A cross-section of a ball bearing showing exaggerated diametral clearance and end float.*

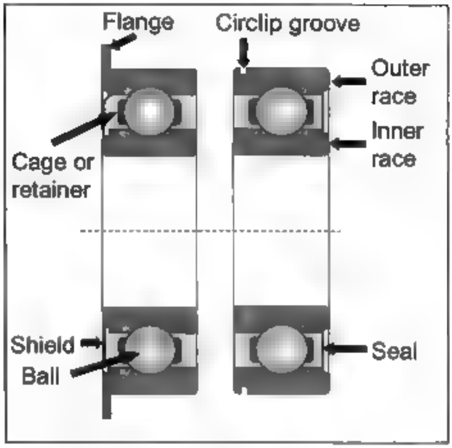

Figure 7. *The terminology used to describe the parts of a ball bearing.*

shortcomings. Occasionally a modeller may require individual balls without the associated races and cages. A good example is the use of balls in a Congreve clock. These balls are readily available in a wide range of sizes.

In a perfect world, ball bearings would be made with zero clearance between the balls and the races but in the real world there is always a degree of diametral clearance which results in some end float. This is shown in *Figure 6*. A later section in this chapter, on pre-load, shows how this diametral clearance and the resulting end float may be reduced to acceptably low levels.

In high-speed applications, such as model jet engines, the centrifugal forces generated by the balls alter the contact angle at the inner and outer races. Ceramic balls such as silicon nitride (40% of the density of steel) are for this reason now preferred for these applications; in addition to their ability to function at high temperatures and their similar wear characteristics to bearing steel, they do not crack or shatter. Ceramic bearings are discussed further in Chapter 4.

Cages

Common types of cage used for miniature ball bearings are either two-piece ribbon or one-piece crown; the latter is better suited to low torque, low-speed applications. Cages may be made from brass, chrome steel or stainless steel and more recently plastic such as nylon, often glass-reinforced, acetal, phenolic laminates, Delrin, Torlon or PEEK. Bearings with a bore size over 10mm usually employ a two-piece steel-riveted cage to allow for greater loads, vibration and acceleration.

Full-complement bearings are cageless but with extra balls that allow for higher loads at slower speeds than caged bearing. They have a filling slot on the edge of either the inner or outer ring to enable extra balls to be inserted during assembly. Without a cage, the balls are no longer separated and can thus make contact with each other. At the points of contact the balls are moving in opposite directions, increasing both friction and wear.

Shields and seals

The main reasons for shielding or sealing any bearings are to prevent contaminants entering the bearing and to contain any lubricant. Non-contact shields may be

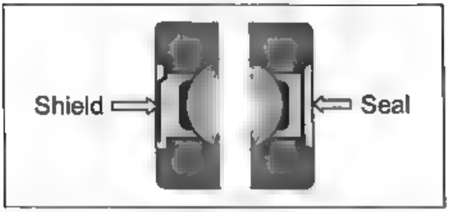

Figure 8. *Bearings may be fitted with one or two metal shields or rubber seals to protect them from dirt or to prevent liquid leakage.*

made from steel, often stainless, rubber or occasionally felt. Contact seals, on the other hand, are usually made from rubber, Teflon or Viton, reinforced either with metal or GRP. Stainless-steel bearings are ideal for applications where corrosion is expected to be a problem.

Types

Ball bearings come in many different sizes. There are single row, thin single row and double row (for heavier radial loads, twin-row ball bearings provide a superior specification) and there is a huge range of diameters for the inner and outer races to suit a large number of shaft sizes and housing diameters. There are bearings designed to take significant axial loads,

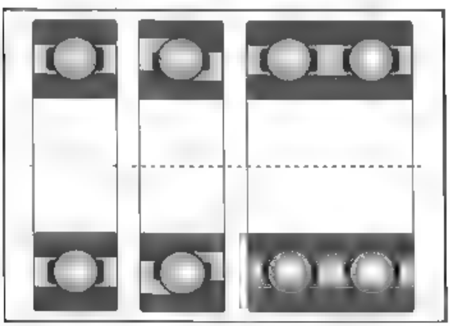

Figure 9. *Three different types of ball bearing: from left to right, a single row, angular contact and double row.*

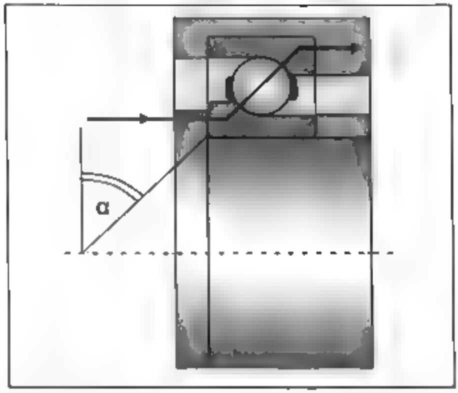

Figure 10. *The way axial loads are carried by an angular-contact ball bearing.*

full-complement cageless bearings and those with or without a flange or snap-ring groove. Thin-section bearings offer reduced weight and rolling resistance as well as needing a smaller space envelope.

Angular-contact ball bearings

Angular-contact ball bearings designed only for radial loads use inner and outer races so shaped that a radial load passes through the bearing. The races are asymmetric on the bearing axis one is shown in *Figure 9*. This enables angular-contact bearings to deal simultaneously with both radial and axial loads. It should be noted, however, that most radial designs will also support a modest axial load.

The axial load-carrying capacity will increase as the contact angle α (shown in *Figure 10*) becomes larger. The contact angle lies between the line perpendicular to the bearing axis and the line joining the two contact points of the ball and the raceways along which the axial load is transmitted from one raceway to the other. The larger the contact angle, the higher the axial load that the bearing can support but the lower the radial load.

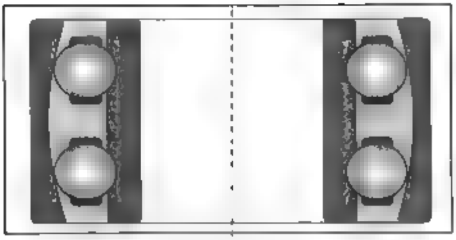

Figure 11. *Cross-section through a self-aligning ball bearing.*

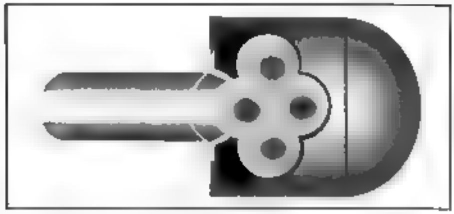

Figure 13. *A pivot bearing design by Timken, very similar to Leonado's design in Figure 12*

Self-aligning ball bearings

By using two rows of balls and a common concave-shaped raceway as the outer ring, these designs of bearing self-align and are insensitive to small angular misalignments of the shaft in relation to the bearing housing. They are particularly suited to applications where significant shaft deflections or misalignment are likely. This type of bearing also offers extremely low levels of friction, minimising heat generation, particularly at high speeds.

Thrust ball bearings

There are numerous ways of containing thrust at right angles to the axis of rotation. Half a millennium ago, Leonardo da Vinci sketched a design for what today would be called a pivot bearing. A copy of his sketch is shown in *Figure 12* and a modern pivot bearing similar to his original design is illustrated in *Figure 13*. However, the type of thrust bearing more likely to be used by model engineers is shown in exploded view in *Figure 14*.

A single-direction thrust ball bearing typically comprises a shaft washer, a housing washer and a ball-and-cage thrust assembly. Double-direction thrust ball bearings still employ a single shaft washer but in addition have two housing washers and two ball-and-cage thrust assemblies identical to those of the single direction bearings.

Some smaller sizes can have either a flat seating surface on the housing washer or a spherical seating surface

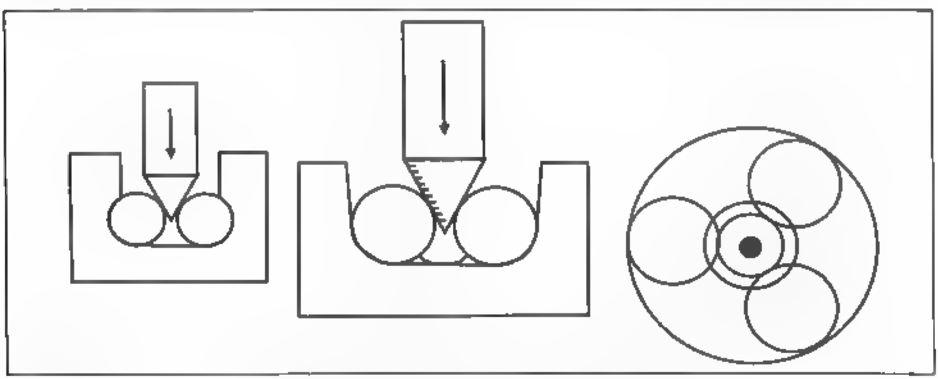

Figure 12. *From Leonardo's sketch of a ball race able to take thrust and radial loads.*

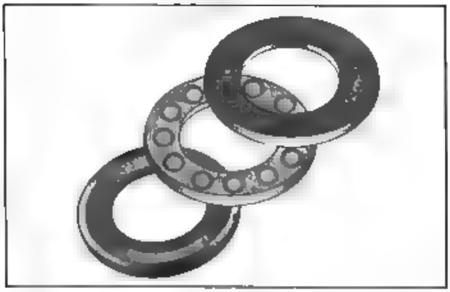

Figure 14. *The top race, balls and cage, and bottom race of a thrust ball bearing.*

which, as well as a matching spherical-seating washer, helps compensate for any misalignment. Both types of thrust ball bearings can accommodate axial loads in one direction but must not be subjected to any radial load whatsoever; this is usually not a problem for model engineers.

Lazy Susan bearings
A specialist form of thrust bearing is the Lazy Susan bearing, which comprises a pair of interlocked plates separated by ball bearings to provide smooth turning and maximum stability of the load it supports. Usually employing steel balls running in plastic or metal races, these bearings are designed for applications such as revolving shelves in kitchen cabinets, turntables, serving trays, revolving seats, cake stands and book shelves. Popular sizes can range from as little as 75mm diameter to over 400mm. Their use is particularly applicable to models of fairground carousels and rotating bases to show off static models.

Miniature ball bearings
Miniature deep-groove radial ball bearings are available open, shielded or sealed, with or without a flange, and some with bore sizes down to just 0.6mm. At this small size they are often called 'instrument bearings'. Available in chrome, stainless steel or as hybrid ceramic bearings, these miniature bearings can withstand considerable radial loads and some thrust loads in both directions. Inevitably, the greater the degree of miniaturisation, the higher the price is likely to be.

Figure 15. *A pillow block with built-in ball bearing and grease nipple. Photo courtesy the Timken Company.*

Other ball-bearing configurations
Ball bearings can be mounted in a number of different fittings. *Figure 15* shows one that comes built into a pillow block; a pair of these blocks is ideal for holding a lay shaft.

Roller bearings

Early ball races resulted in high levels of friction when carrying heavy side-loads, common when a vehicle is turning. The situation was often exacerbated by a build-up of heat if there was insufficient lubrication, leading to bearing failure. Despite the widespread use of rollers for moving heavy loads during a number of millennia, it was Henry Timken, a German émigré living in the USA and running his own carriage factory, who devised the first roller bearings.

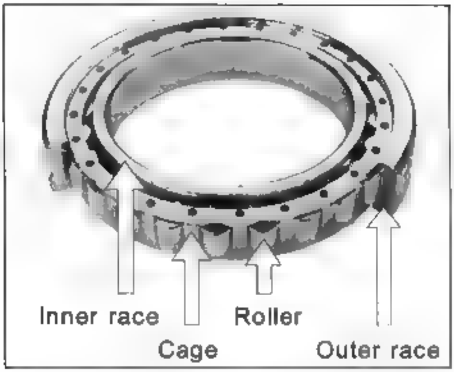

Figure 16. *A cut-away single-row roller bearing showing the main components. Photo courtesy the Timken Company.*

His 1898 patents dealt with their application on carriage and car axles. The company that bears his name was founded in the last year of the nineteenth century and has continued to flourish ever since with the growth in bearing demand for cars and trucks, trains and aircraft as well as for more specialist applications, such as lifts, machine tools and automated production involving conveyor belts and robotic arms.

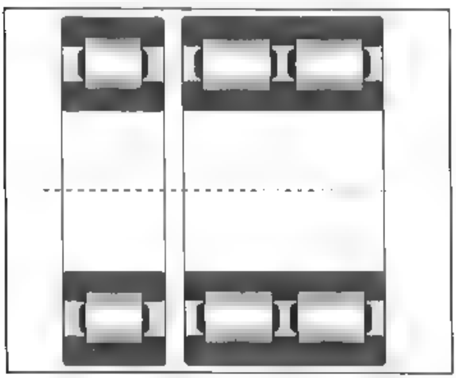

Figure 17. *A cross-section through single- and double-row roller bearings.*

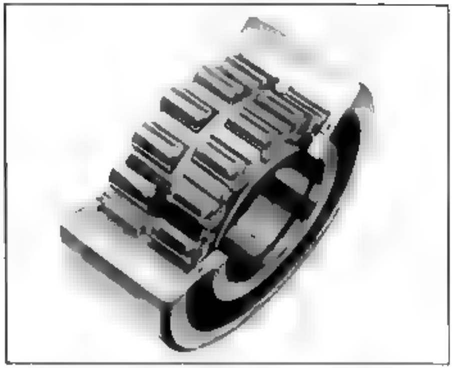

Figure 18. *Cutaway of a double-row roller bearing. Photo courtesy Schaeffler UK.*

Roller bearings are constructed in a similar way to ball bearings, except that clearly it is much easier to manufacture precise cylindrical rollers than perfectly spherical balls. A typical roller bearing comprises an inner and outer race and a number of rollers retained in position by a cage. The fundamental design of roller bearings enables them to accept higher levels of radial loading than ball bearings of equivalent size. And, of course, double-row roller bearings are available to carry the highest loads.

Tapered roller bearings

Tapered bearings are similar to ordinary roller bearings but with the axis of the rollers tilted so that it is not parallel to the axis of the shaft at the centre-line of the bearing. And, of course, the rollers themselves are tapered rather than a cylindrical shape. These bearings consist of four parts: the cone or inner ring, the cup or outer ring, the tapered rollers and the cage that retains the rollers.

Angling the rollers allows the tapered roller bearing to carry combinations of radial and axial loads. The greater the angle between the outer race and bearing

Figure 19. *The components that make up a single-row tapered roller bearing. Photo courtesy the Timken Company.*

centre-line the greater is the ratio of axial to radial load capacity. This is shown in *Figure 20*. The capability to carry radial loads, axial or thrust loads, or a combination of both, enables tapered roller bearings to be used in many applications. This type of bearing is often supplied with the outer race separate from the rest of the bearing to allow greasing prior to fitting and accurate pre-loading.

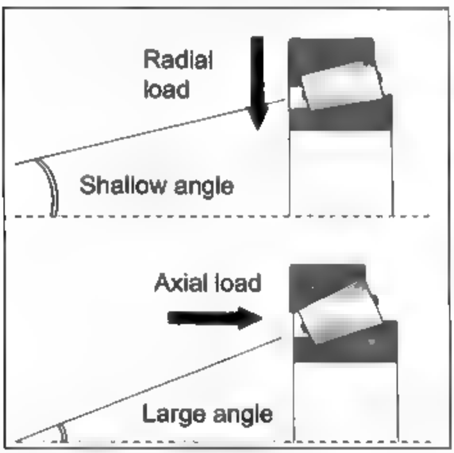

Figure 20 *The angle of the rollers depends on the expected radial and axial loads.*

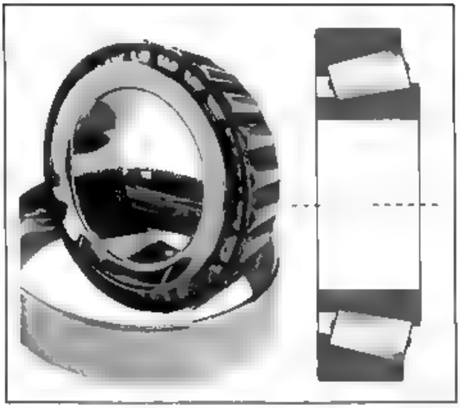

Figure 21. *Left, a photo of a tapered roller bearing, photo courtesy the Timken Company, and right, a cross-section through the bearing.*

Self-aligning roller bearings

In order to accommodate a degree of out of alignments of a shaft, a self-aligning roller bearing employs barrel-shaped rollers and appropriately curved inner surfaces of the races themselves. Such a twin-row self-aligning bearing is shown in the right-hand illustration in *Figure 22*.

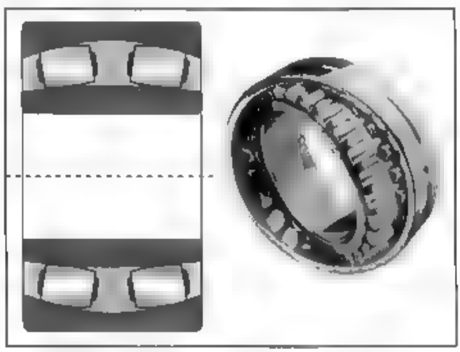

Figure 22. *Left, cross-section through a self-aligning roller bearing; right, view of a self-aligning roller bearing. Photo courtesy the Timken Company.*

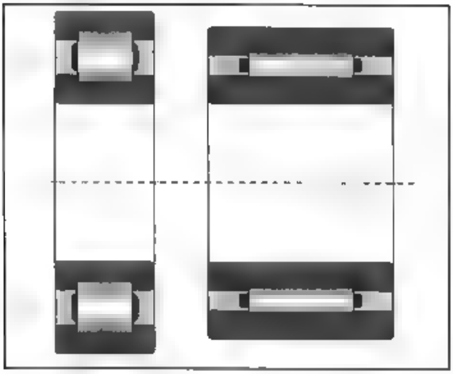

Figure 23. *Comparison of the cross-sections, left, of a roller bearing and, right, a needle bearing.*

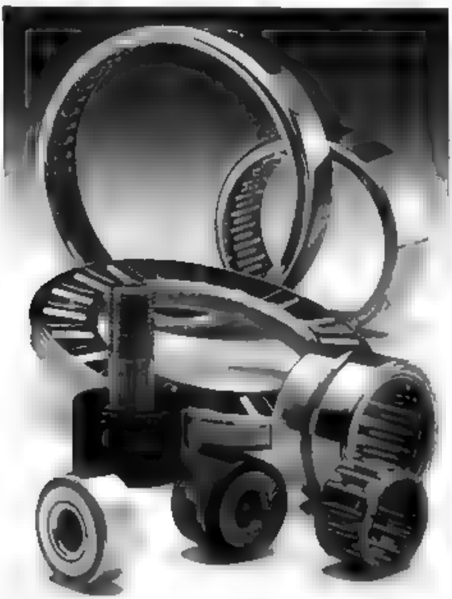

Figure 24. *A selection of needle-roller bearings including bearings with no races, one race and two races as well as a thrust needle bearing Photo courtesy the Timken Company.*

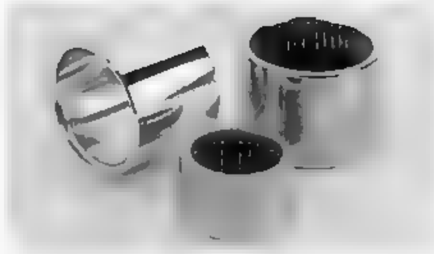

Figure 25. *Considerable space-saving is possible using of needle-roller bearings. Photo courtesy the Timken Company*

Needle bearings

The development of needle bearings resulted from the need for more compact rolling bearings and the desire for greater surface contact area. The rollers in a needle bearing are both smaller in diameter and longer in length than the rollers in conventional roller bearings. For applications where space is severely limited, needle bearings can be fitted directly onto a hardened steel shaft to save the space occupied by the inner race, or even into a hardened housing as well, without either the inner or outer race.

The difference between the diameter of the shaft and that of the bearing are minimised at some cost to the fatigue life of the bearing. Thus needle bearings are well suited to shafts that undergo oscillatory rather than continuous rotation. However, with the majority of models, small size rather than long life is usually the priority so it is always worth considering using a needle bearing where space is at a premium.

Remember that standard needle bearings are not designed to take any axial thrust and should not be employed in applications where end-location of a shaft is needed However, thrust needle bearings are available that have been

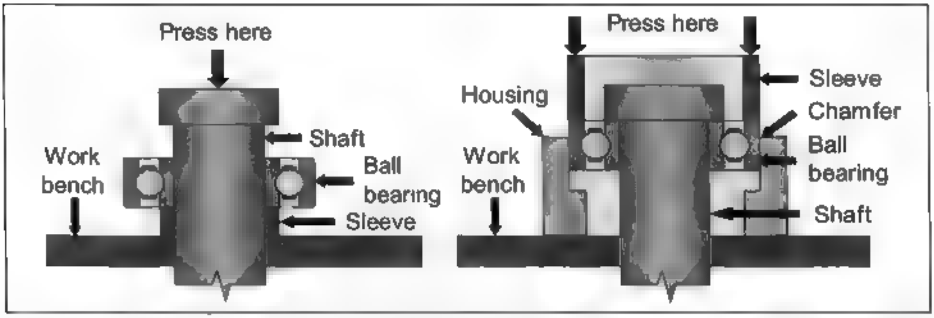

Figure 26. *Left, how to fit the shaft to a ball bearing by supporting the inner bearing ring while pressing on the shaft; right, fitting a bearing on a shaft into the bearing housing by pressing against the outer ring. The same approach should be taken with roller and needle bearings.*

specifically designed to take axial rather than radial loads and one is illustrated in the lower centre of *Figure 24*.

Fitting bearings

It is important to obtain the correct fit for any ball, roller or needle bearing, both on the shaft and in the bearing housing. The aim of getting the correct fit is to prevent the inner race creeping on the shaft and likewise the outer race creeping in the housing. Should creeping occur, the temperature of the bearing will rise due to slipping abrasion. Other dangers include looseness of the inner race on the shaft and/or the outer race in its housing, as well as the generation of small particles of metal that will enter the bearing, causing it to become noisy and eventually to fail. Typically a good interference fit prevents creeping, but the possibility of differential expansion due to temperature changes should be born in mind. An interference fit describes the tightness between a shaft and bearing bore or a housing and bearing outside diameter. An interference fit may be defined as a loose fit, light interference fit or interference fit.

When installing a bearing that needs an interference fit, force should only be exerted against the inner or outer ring that is being installed. When pressing a bearing onto a shaft, the pressure should be applied against the inner ring. When pressing a bearing into its housing, the pressure should be against the outer ring. Examples of how to do this are shown in *Figure 26*, using suitable diameter sleeves and fitting the shaft itself through a hole in the workbench. *Figure 27* shows the situation where the bearing has to be pushed onto the shaft and into the housing at the same time. Always apply pressure

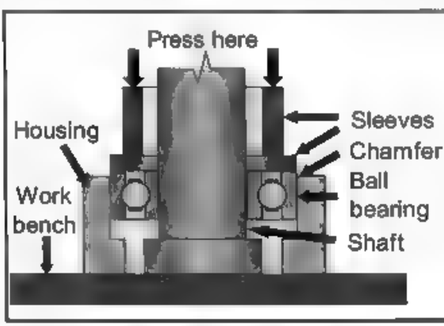

Figure 27 *Simultaneously pressing the bearing onto its shaft and into its housing.*

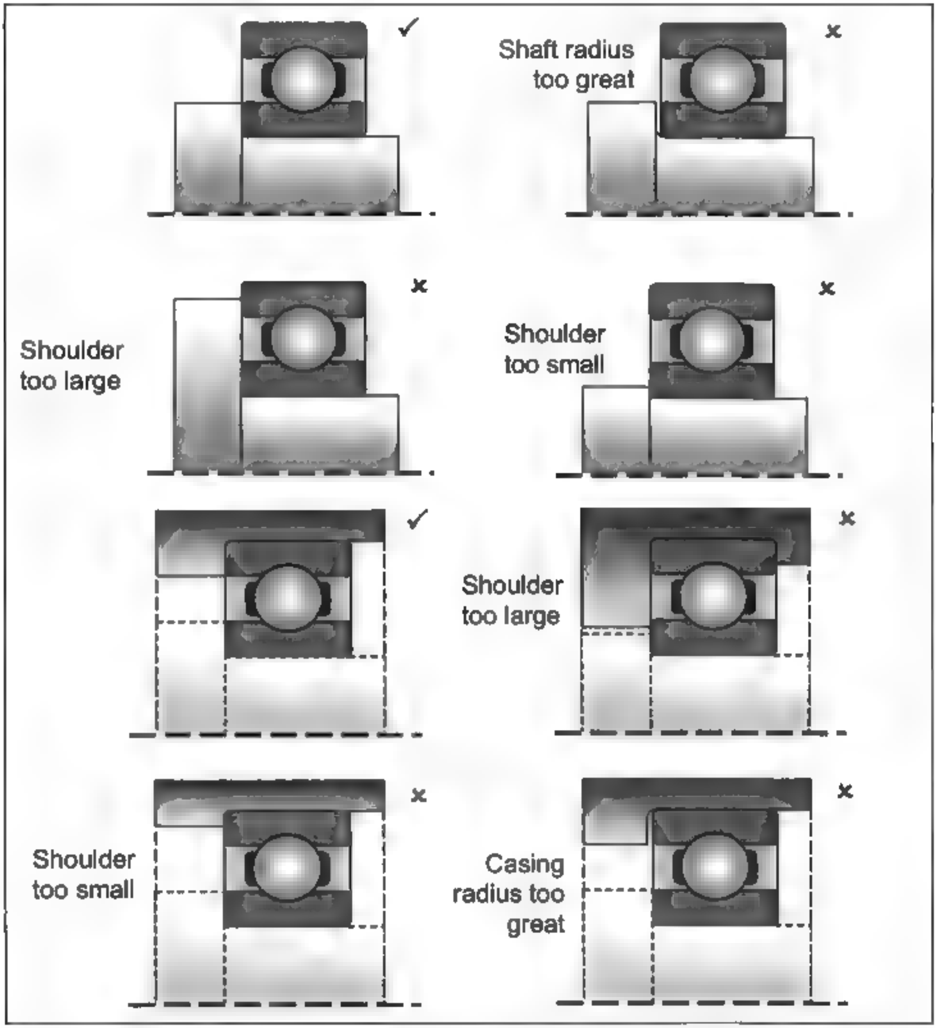

Figure 28. *Two right and six wrong ways of fitting a ball, roller or needle bearing to a shaft.*

slowly and evenly. And chamfer or round the entrance to the bearing housing as well as the shaft end to ease installation of the bearing. It is essential that the sleeves have no contact with the bearing cages to avoid damaging them. Any sign of a bent bearing cage makes the bearing unusable. Special care needs to be taken when installing needle bearings due to their narrow footprint when viewed end-on.

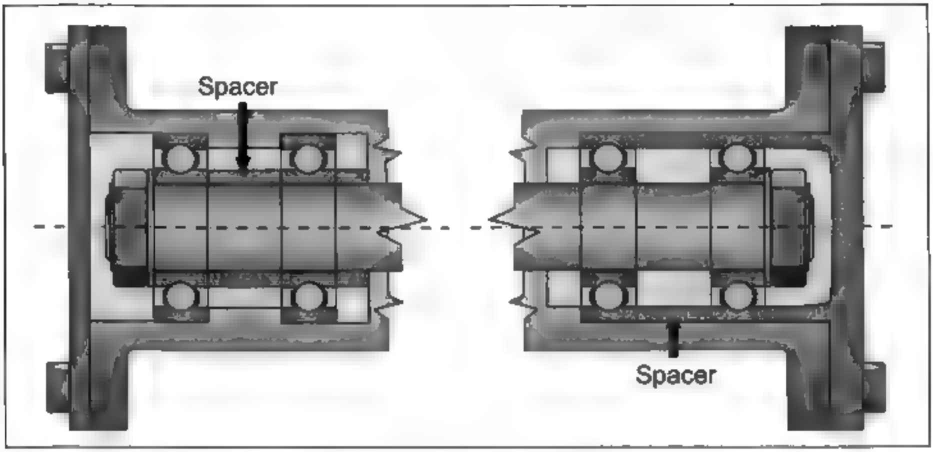

Figure 29. *Two alternative ways of using a spacer with a pair of ball bearings.*

There is a right and wrong way to fit any ball, roller or needle bearing. If the bearing is to fit on a shaft, a shoulder needs to be provided to support the inner race. *Figure 28* shows correct solutions designated with ticks as well as incorrect ones indicated with crosses:

1. Having too large a shoulder.
2. Having too small a shoulder.
3. Leaving a radius of curvature to large between the shaft and the shoulder or between the casing and the shoulder, preventing the bearing from seating against the shoulder.

Spacers can be used when installing pairs of bearings and *Figure 29* shows two alternatives.

Shaft and bore retaining rings are available in a wide range of sizes and can be readily fitted into suitably sized grooves in the shaft or housing. If gluing bearings in place using a cyanoacrylate retainer such as Loctite 603, taking care not to get adhesive into the bearing. Another solution is to use a flanged bearing and retain it in place with a bolted-on plate. This is demonstrated in *Figure 30*.

Bearing pre-load

When a ball or roller bearing is used in an application such as a lathe or its motor, there should be no radial clearance when an axial load is applied. Any radial clearance will cause vibration of and noise from the balls in the bearing and there will inevitably be slop in the bearing. Pre-load is used to avoid these short-comings.

Pre-load is a force applied in an axial direction and may be produced by tightening the locking device that holds a bearing in place. The optimum amount for any particular ball bearing will depend

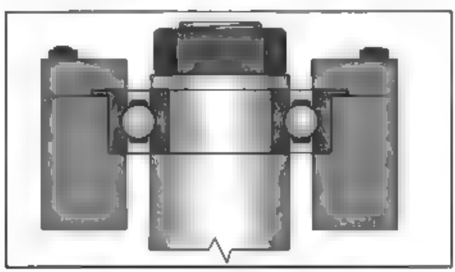

Figure 30. *A flanged bearing held in place with a bolted-on cover plate.*

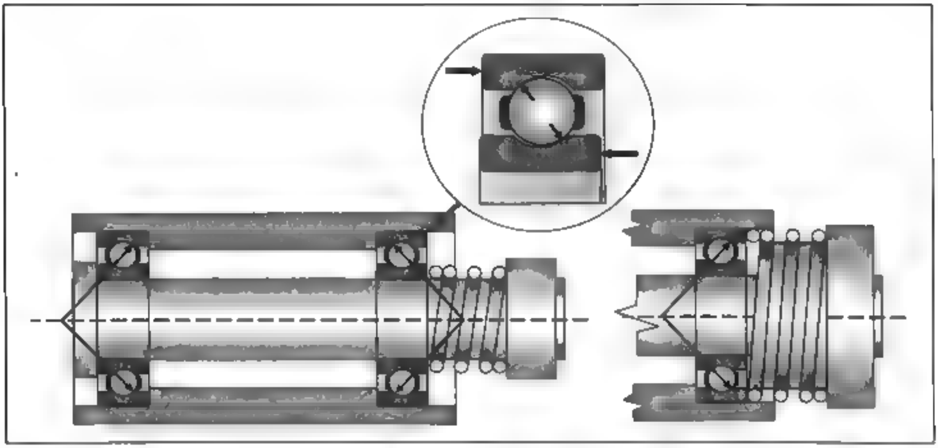

Figure 31 *Two alternative ways of pre-loading bearings using a spring to provide the load in either of two directions. The expanded view shows the loadings on the balls and races.*

on its size and construction. Excessive pre-load will reduce the life of the bearing, and increase the amount of noise produced, the heat generated and the bearing starting and running torque. On the other hand, insufficient pre-load will cause abrasion and eventually corrosion of the races. In the applications above, the required amount of pre-load is usually specified by the equipment manufacturer.

Two different methods of obtaining pre-load are solid and spring pre-load. Solid pre-load is obtained by mechanically locking the races in position, with shims if needed, while under an axial load. The disadvantage of this method is the high variation in pre-load as temperature changes and its reduction as the bearing wears. Pre-load can also be provided by a suitable spring: a coil or a washer. The advantage of a spring is that it maintains a consistent pre-load as temperature varies but generally solutions are more complex, space-consuming and less stiff. Two examples of using a spring to provide pre-load are shown in *Figure 31*. All pre-load should be applied with minimum force to provide the desired result. Furthermore, spring pre-loading is not suitable for use where the axial load can change from one direction to the other.

An alternative is to employ pre-load ground-duplex bearings. In contrast to the other two adjustment methods, duplex bearings offer the benefit of achieving built-in pre-loading. Matched pairs of duplex bearings have both their inner or outer ring faces precisely relieved. When a pair of bearings is clamped together at installation, the offset faces provide a permanent pre-load in the duplex pair.

Duplex bearings are usually selected when there is a need for predictable rigidity, both radial and axial. Duplex bearings can withstand bidirectional thrust loads as well as heavy loads in a single direction. There is, however, often a speed limit for duplex bearings due to the amount of heat generated by the rigid pre-load.

Figure 32 shows three possible configurations of duplex bearings: face-to-face,

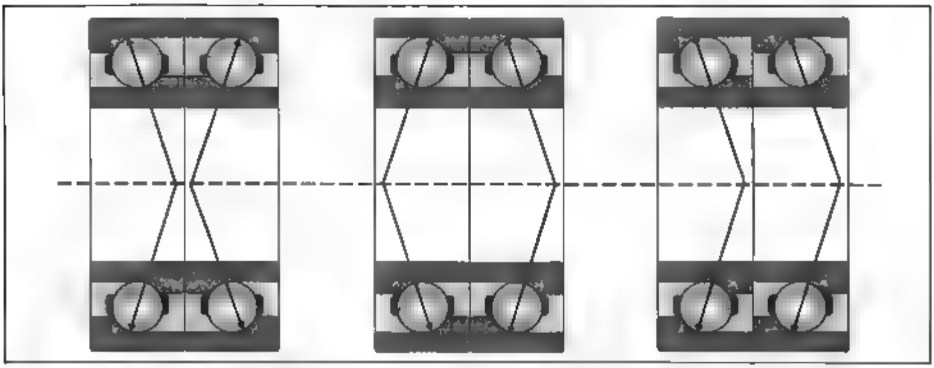

Figure 32. *Three different configurations of duplex From left to right: back-to-back with the inner faces clamped together, face-to-face with the outer races clamped together and tandem.*

back-to-back and tandem. The first two types are capable of accommodating axial loads in either direction. But the tandem pairing is capable of accepting a very high axial load only in one direction; thus pre-loading is essential against another single or duplex bearing.

Two-part roller bearings
Many tapered roller bearings are supplied as two separate parts: a cone assembly comprising a conical inner race, cage and rollers plus a separate outer race. This enables each bearing to be individually adjusted during installation and maintenance. It also allows the bearing to be readily grease-packed prior to installation.

To achieve the right setting, the bearing should initially be adjusted with the correct end play and pre-load. It is very difficult to obtain an accurate measurement of the latter. End play implies a degree of clearance between the bearing's rollers and races and may be measured as an axial movement using a dial gauge. In a fully pre-loaded bearing assembly all raceway surfaces are in contact, providing zero axial clearance. Since two-piece bearings are most likely to be found on machine tools, the settings are usually provided by the manufacturer. Two-piece bearings may also be employed on large-scale models where advice may be obtained from the bearing-manufacturer's catalogue or web site.

Bearing problems and solutions

The most common bearing problems are the generation of noise, excessive heat

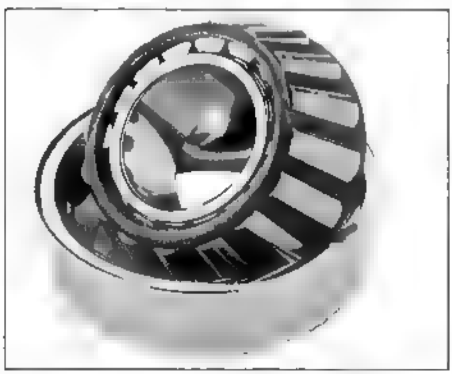

Figure 33. *A two-part roller bearing. Photo courtesy the Timken Company.*

	Radial load	Axial load	Radial & axial loads	High speed	Low friction	Quiet running
Ball						
Single row	S	S	S	E	E	E
Double row	S	S	S	S	G	S
Self-aligning	S	P	P	G	G	G
Angular contact	G	S	G	G	G	G
Thrust	N	S	N	S	S	P
Roller						
Cylindrical	G	N	N	E	G	S
Double row	E	N	N	E	G	G
Needle	G	N	N	S	P	S
Taper	G	G	E	[illegible]	S	S
Self-aligning	E	S	E	S	S	S
Thrust	N	E	S	S	S	P

Table 1. The comparative suitability of different types of ball and roller bearings to particular needs. E = excellent, G = good, S =satisfactory, P = poor, N = not recommended.

and vibration. The first two are often caused by inadequate lubrication. Other causes of excessive noise include: too small or excessive clearances, poor-fitting bearings, varying clearance with temperature change, excessive load, damaged races or rolling elements, corrosion and the ingress of dirt. Vibration is usually the result of flaking of races and rolling element, ingress of dirt, excess clearance or poor location of the bearings. Over-heating is commonly caused by too little clearance, poor bearing location, over-loading or bearing creep.

Solutions include: replacing the bearings, improving lubrication, ensuring correct clearances, fitting, fixing and mounting methods and, least likely for models, reducing loads and avoiding shock loads.

Obtaining bearings

Figure 34 indicates which types of rolling bearings are suitable for which types of application. There are many suppliers of ball, roller and needle bearings, both in the UK and around the world. Their details can be found in Yellow Pages but many of them also advertise and have web sites on the Internet. Chapter 6 gives more advice on selecting and purchasing bearings and a list of useful contacts is given at the end of this book.

CHAPTER 3

Linear and oscillating bearings

Introduction

So far, consideration has been given to what most model engineers mean when they talk about bearings: solutions that allow shafts to turn in their fittings with a minimum of friction. However, the same considerations that are important in the design and use of such bearings are also applicable to linear motion where two parts of a model or other machinery move in a linear straight-line manner or an oscillating back-and-forth motion, rather than rotating. Thus as well as the linear bearings that may spring to the average model-engineer's mind, such as machine-tool slides and crossheads, details are given of the way that friction and consequent wear may be minimised in such areas as pistons and cylinders, valve gear and glands, axle boxes, shock-absorbers and oleo legs.

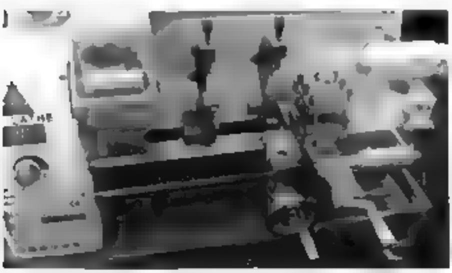

Figure 1. The slides on a lathe are a classic example of linear bearings.

As in the case of rotary bearings, a distinction is drawn between whether the forces occurring are transmitted by means of rolling or sliding elements, although the latter are by far the most commonplace.

The need for linear sliding bearings is commonly found in machine tools where the bearings will be plain ones, usually made from cast iron. As with rotating bearings, there are also linear bearings that employ balls or rollers. In precision equipment, where the emphasis is on accuracy and rigidity, the use of linear balls or rollers is the norm. These types of bearing are discussed towards the end of this chapter.

While rotating-bearing elements are separated either by a film of lubricant or, in the case of ball and roller bearings, by rolling parts, in plain linear bearings the movable part slides on or within a static component, such as a cylinder, gland or guide way Depending on the application, the sliding layer moves in contact with a film of lubricant on the rigid static component. Lubrication is carried out by a variety of means, including manual application of oil

or grease, automatic lubrication systems, oil in the steam or petroleum-based fuel, or even lubricants embedded in the sliding layer.

Many factors need to be taken into consideration when selecting a linear bearing, such as the load, acceleration, sliding speed, amount of movement, the environment, vibration levels, methods of mounting and the expected amount of use. Other important considerations include contamination, corrosion and the means of providing suitable lubrication. One difficulty is that linear motion is not continuous and this can lead to two problems. The first is found, for example, on lathes, where the rate of wear near the headstock is almost invariably much greater than anywhere else along the slide. The second, with oscillating motion, is found with a crosshead, the speed of movement is greatest in the centre of the slide and becomes zero at each end as the crosshead changes direction. This again leads to uneven wear.

Cylinders, pistons and piston rings

The first items to be considered are the pistons, cylinders and piston rings used in static steam engines and steam locomotives, as well as those employed in internal-combustion engines. The choice of suitable materials and how to finish them to get long-lasting and smooth-running 'bearing' surfaces is analysed.

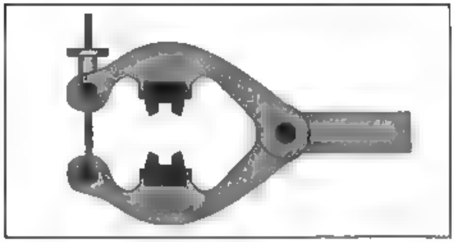

Figure 3. An external hone suitable for finishing a piston or uncut piston ring.

Cylinders

Since a cylinder is an integral part of the bearing combination, comprising the cylinder and piston or piston ring, it is essential that is provided with a quality finish, whether it is to be part of a steam engine or an internal-combustion engine. Normally a cylinder is bored to approximate size using a boring tool, but as explained in Chapter 1, this does not provide an adequately smooth surface finish. Thus honing is the preferred method of producing a quality surface in any cylinder.

Honing

It is normal practice to provide the ultimate finish for a cylinder by using an internal hone. Honing is a final surface-finishing operation. In the case of cylinders, abrasive stones are used to remove minute amounts of material in order to smooth any irregularities in the surface and to improve the circularity of

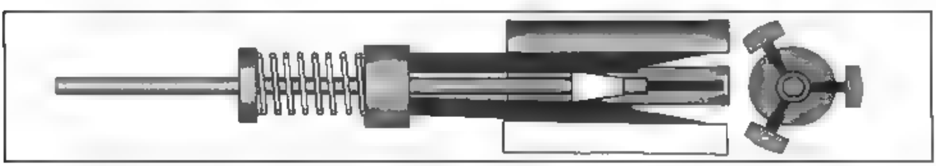

Figure 2. The plan and cross-section of an internal hone with three spring-loaded abrasive stones, suitable for honing a cylinder.

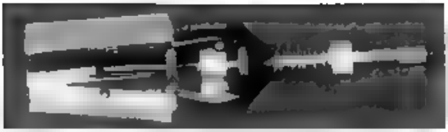

Figure 4. A commercially available hone.

the bore. The cylinder is usually fitted in a lathe chuck, carefully centred, and the hone moved back and forth inside the cylinder as it rotates. It is lubricated with honing oil, until the desired finish and size are achieved. A similar approach can be taken with the piston and/or piston rings but using an external hone, though lapping (see Page 9) of these components to achieve a good fit is more common.

Any individual hone can only cover a specified range of diameters. One popular UK supplier offers three internal hones that cover the range of diameters from 12.5mm to 178mm (½" to 7") and two external ones covering up to 25mm (1") and up to 50mm (2"), as well as spare stones for both types and all sizes.

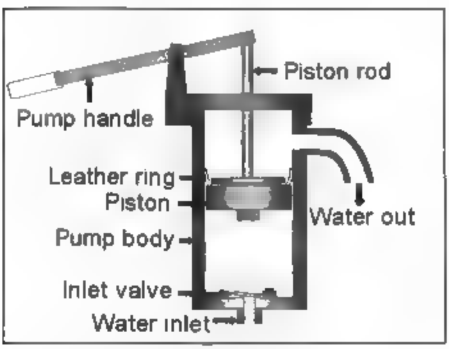

Figure 5. A water pump fitted with a leather piston ring that doubles as a valve on the downward piston stroke.

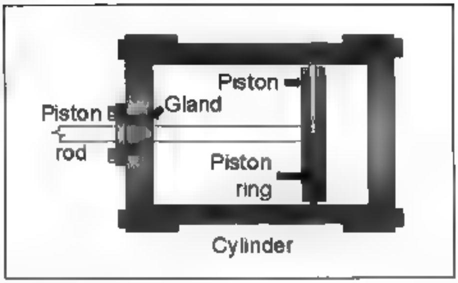

Figure 6. Cross-section through a steam-engine cylinder and piston fitted with a cast-iron piston ring.

Pistons and rings

Water pumps were probably some of the earliest machines to use piston rings, made from hemp or flax rope. But in the middle of the seventeenth century, Robert Boyle made a pump that used a leather piston ring, the water maintaining the pliability of the leather to provide an effective low-friction seal. However, even in the early days of the steam engine, steam leakage was a problem until, in the early 1850s, James Ramsbottom came up with a way of sealing the piston against the cylinder wall without any increase in friction. He designed a piston with grooves that could be fitted with cast-iron split rings of somewhat larger diameter than the piston and sprung so that they would press against the cylinder walls. By using three rings to compensate for slight variations in the surface of different parts of the cylinder, this provided an effective seal against steam loss. Furthermore, the use of these rings enabled the weight of the piston to be dramatically reduced and when Ramsbottom's rings were first fitted to locomotives, they ran without problems for several thousand miles.

Figure 7. The cylinder, piston and piston rings for a Stuart Victoria beam engine.

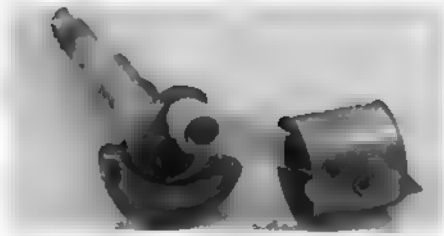

Figure 8. A model aero-engine piston and single ring plus conrod and crankshaft.

Steam engine pistons and rings

Cast iron and gunmetal are both popular materials for making steam-engine pistons and cylinders, though two different metals are needed to minimise wear. Phosphor-bronze pistons are also popular. Steam engines use a variety of different materials for piston rings, depending on the size and power rating of the engine and the likely time the engine is expected to spend running.

Because the temperatures within the cylinder are low compared to internal combustion engines and the impact of lubricating oil in the cylinder is much less severe than in the case of spark- or glow-ignition engines, the materials used to make steam-engine piston rings operate in a relatively benign environment. The first choice for steam-engine piston rings is almost inevitably cast iron but alloy steels containing nickel and/or chromium are also excellent choices. The rings should preferably have scarfed joints. Such rings may be lapped in the cylinders to provide a quality fit; the lapping process is described in Chapter 1.

Historically, braided graphited asbestos was a popular choice for piston rings but for health reasons this is no longer available; graphite-impregnated yarn is a reasonable modern substitute. Other choices include PTFE yarn and O-rings. It is essential that the piston/ring combination is a steam-tight fit within the cylinder without being too mechanically tight; a clearance of about 0.025mm (0.001") is about right for a small engine.

PTFE O-rings have several advantages when used as piston rings. The material offers an exceptionally low coefficient of friction yet is sufficiently elastic to enable easy fitting of the rings. For a plastic material, it can tolerate a wide range of temperatures (up to 260°C and as low as -200°C) while being highly age-resistant. Viton is a popular PTFE brand used to make O-rings that are suitable as 'piston rings' on smaller steam engines.

Internal-combustion engine piston rings

Of course, not all model reciprocating internal-combustion engines use piston rings. A classic case is the ABC type of glow-plug engine where an aluminium piston runs in a chrome-plated brass liner. Another solution is to use a cast-iron piston lapped to fit the cylinder.

However, the vast majority of engines do employ rings. The piston ring is invariably a split ring that fits into a groove in the outer diameter of a piston. It serves four purposes: to provide a sliding bearing surface between

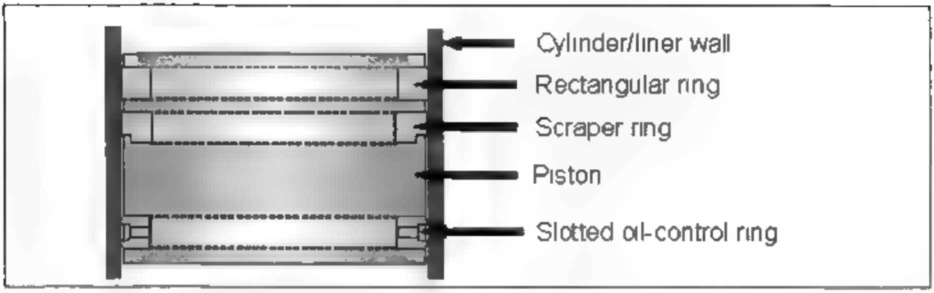

Figure 9. Cross-section through a cylinder and piston fitted with different types of piston ring.

the piston and the cylinder or cylinder liner, to transfer heat from the piston to the sides of the cylinder, to maintain a seal between the piston and the cylinder, and finally to control the passage of oil from the crankcase to the cylinder head. Rings are usually grouped into two classes: those that are used to maintain compression and those that help to control the lubrication of the ring/cylinder interface.

The piston-ring gap compresses to a few hundredths of a millimetre (a few thousandths of an inch) when inside the cylinder. The size of end gap in a ring is critical. Too small a gap will be taken up completely due to the heat of combustion and result in the piston ring seizing. Too large a gap will reduce compression, increase oil consumption and may result in any spark or glow plug becoming oiled up and failing to ignite the fuel/air mixture in the cylinder. Full-size engines usually have three rings fitted to each piston. The top two are primarily for compression sealing though they do provide some oil control, while the bottom ring controls the oil supply to the cylinder or liner and controls the lubrication to the upper compression rings.

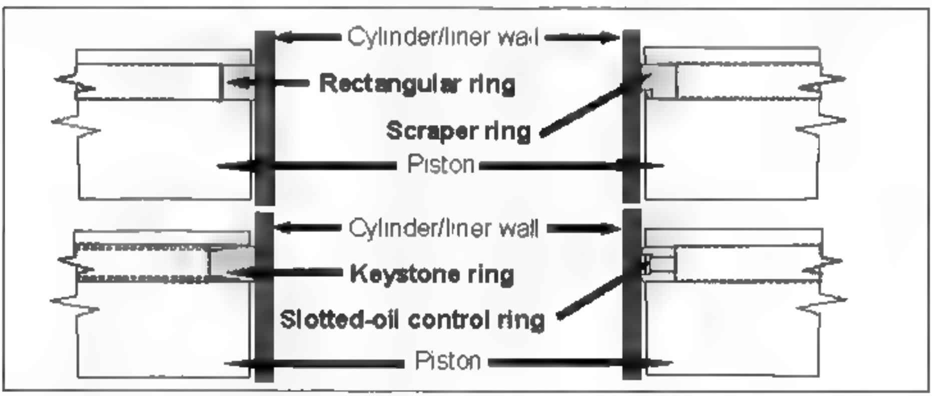

Figure 10. Four popular types of ring: a rectangular ring, a scraper ring, a keystone ring and a slotted oil-control ring.

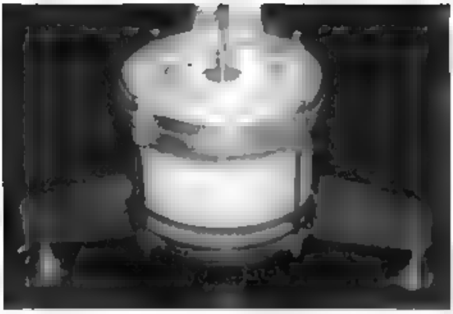

Figure 11. A hot-air engine displacer cylinder showing the polystyrene displacer.

Compression rings usually have a rectangular or near-rectangular cross-section. Oil rings may have a scraper groove at the bottom or a slot in their centre. The purpose of oil-control rings is to leave a microscopically thin film of lubricating oil on the bore as the piston moves. Typical cross-sections are shown in Figure 10.

Piston rings wear as they slide up and down the cylinder bore, though the amount of wear experienced by the typical model tends to be limited. However, they are commonly made of wear-resistant materials, such as cast iron, and full-size ones may be coated or treated by chromium plating, nitriding or a ceramic coating to enhance the wear resistance.

Fitting rings

Whenever metal-to-metal rings are used, it is essential that, just like plain bearings, the adjacent surfaces are lapped to provide the best possible fit. Probably the easiest way to achieve this is to lap the ring, or the piston itself if rings are not fitted, directly in the cylinder using a fine grinding paste. The piston/ring assembly should be moved back and forth in the cylinder and regularly rotated.

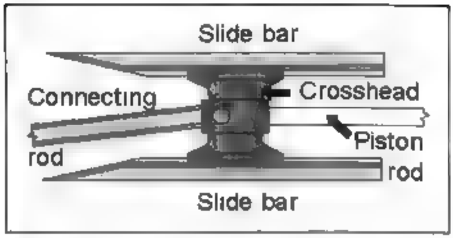

Figure 12. The crosshead provides two linear bearings operating between the slide bars.

The lapping process should be repeated until the ring shows evidence of lapping all around its circumference. An allowance of 0.025–0.05mm (0.001–0.002") should be made for the final lapping process.

Hot-air engines

Hot-air engines employ a wide range of materials for their power and displacer cylinders and pistons. Light weight and low friction are key characteristics for any moving part. The displacers often employ glass, or clear plastic such as Perspex or acetal, for their cylinders and the piston can even be made from expanded polystyrene. But clearances are always large to minimise friction. An example is shown in Figure 11.

Crossheads

The crosshead is a part of many steam engines that involves sliding as well as rotating bearings. Most crossheads will be manufactured in the model engineer's workshop, although, in some cases, a casting may be purchased to reduce the amount of machining necessary or to provide a better match to the look of the prototype crosshead.

The slide bars will usually be constructed from steel, so that a different material is

Figure 13. A traction engine crosshead with built-in lubricators.

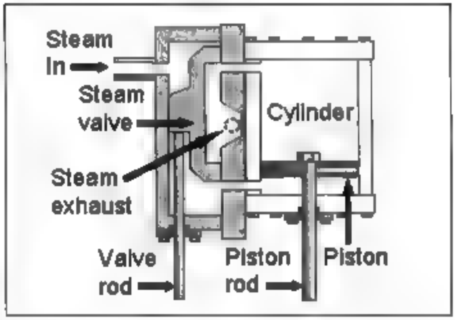

Figure 14. The layout of a classic sliding steam valve, showing where the steam valve contacts its housing.

almost essential for the crosshead itself. This can be made from cast iron, gunmetal, bronze or phosphor bronze or sometimes from brass. Alternatively, if the slide bars are cast iron, then a steel crosshead is a very practical solution. Provision will also need to be made for some lubrication, even if this is done manually. Sometimes, a trunk guide is used instead of slide bars, particularly on models of static steam engines. However, the same choice of materials will apply regardless of the design.

Clearances will depend on the particular application, the size of the model and the materials being used, but up to 0.1mm (0.004") clearance should be allowed between the crosshead and the slide bars.

Steam valves

There are several categories of popular steam valves: slide valves and the less commonplace piston valves. In addition poppet valves are occasionally found in steam engines. The rotary steam valve is covered in the next chapter.

In the first three cases, there is a sliding motion of the valve. In the piston valve, the wearing surfaces can be dealt with in the same way as a normal piston. The slide valve, on the other hand, requires a different approach. Here, the valve is normally sliding against the side of a casting containing the valve ports. It is held in place by steam pressure. Typically, the valve housing is made of

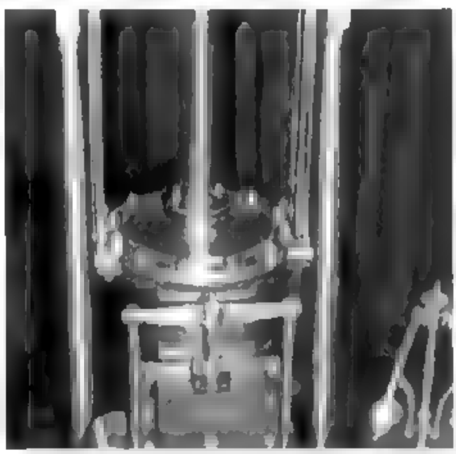

Figure 15. The glands on top of the cylinder and valve gear of this vertical engine are clearly visible.

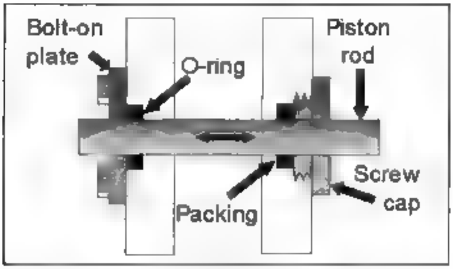

Figure 16. Left, an O-ring held in place with a bolt-on plate; right, packing held with a screw-in cap.

cast iron with a bronze valve, or vice versa. Lubrication of the moving valve is normally provided, as in the case of the piston/cylinder, by oil from a suitable mechanical or displacement lubricator.

Glands

As the piston and valve-operating rods of steam engines emerge from cylinders and valve housings, the glands represent a particular type of linear bearing where the ability to contain steam is particularly important while the bearing function is in itself of somewhat less significance.

Popular alternatives for sealing glands are the use of graphited yarn or PTFE thread as packing within the gland, or a Viton or silicon-rubber O-ring, contained in either a brass or bronze housing with steel piston or valve rods. In these cases the gland needs to be steam-tight up to the maximum operating pressure of the engine itself. Figure 16 shows two ways in which the packing can be contained to enable it to be re-packed or, in the case of an O-ring, to be replaced. Glands are covered in more detail in Chapter 1.

Figure 17. An axle box and horn block fitted to the chassis.

Axle boxes and horn blocks

Axle boxes moving within horn blocks and fitted with suitable springs act as the suspension units for both locomotives and rolling stock. They usually provide just a small amount of vertical movement. Both parts are normally machined from suitable castings, with the horn blocks bolted to the frames of the locomotive, tender, carriage or wagon. The normal rules apply to the choice of materials. The frame and axles will usually be of steel so that brass, bronze, gunmetal or bronze-bushed steel are popular for the axle boxes, with their flanges moving vertically in slots in cast-iron horn blocks. It should be noted that, while the axles running in the axle boxes are conventional rotary bearings, some may experience a high mileage and thus an appropriate choice of materials and a fine finish to these bearing surfaces is required to achieve a long life.

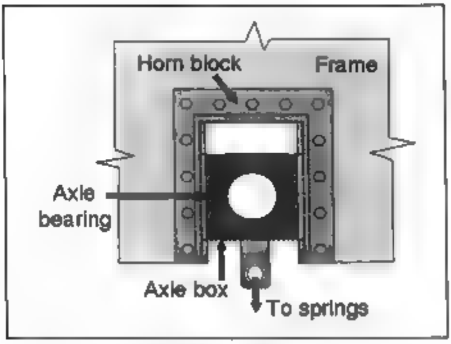

Figure 18. An axlebox and hornblock attached to the frame of a locomotive.

Internal-combustion engine valves

The most commonly fitted valves on internal-combustion engines are poppet valves. Several rotary-valve alternatives are described in the next chapter. Poppet valves need to be made from high-grade steel. Both the valves and guides in which the valves operate must deal with far higher temperatures and pressures than are found in steam engines. As much as a quarter of the heat dissipated by an exhaust valve travels up the stem to the valve guide.

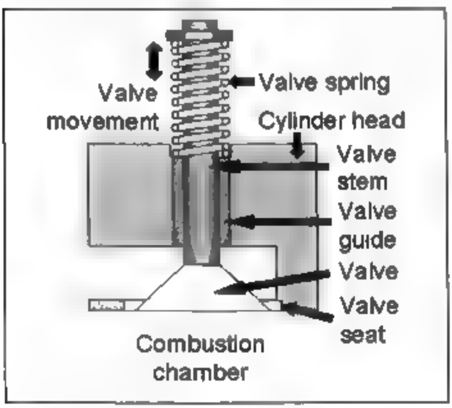

Figure 19. A typical overhead-valve configuration showing the valve guides.

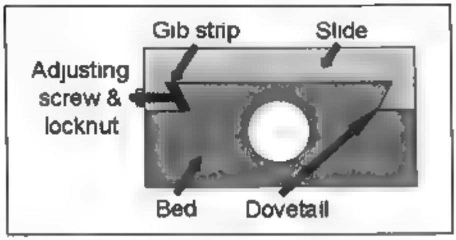

Figure 20. A cross-section through a lathe slide showing the gib strip, adjustment screws and locking nuts.

What is needed are material pairs that combine low friction with high conductivity. Some cast irons and copper-based alloys fit the bill well for the guide material. Valve guides on full-size engines are typically made from materials such as grey cast iron, hard brass, Colsibro (a copper/nickel/silicon alloy), copper/zinc/aluminium alloy, manganese bronze or beryllium copper, and these materials are equally suitable for model engines. Full-size practice is also increasingly turning to sintered valve guides in the continuous search to reduce wear to the guides as well as noxious engine emissions and, almost inevitably, this approach will be taken up by model engineers as well.

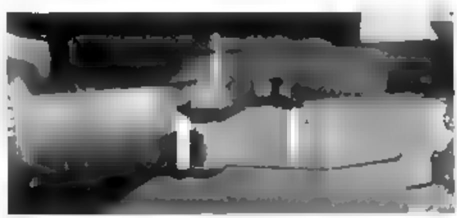

Figure 21. Typical gib-strip adjustment fitted to a lathe slide. The arrows show (left) the end of the gib strip and (right) one of the adjusters.

Slides and gib strips

Machine tools like lathes and milling machines have many sliding parts where the fit of the linear bearing is extremely important if the machine is to produce accurate results. Often both the slide and the bed are made of cast iron with a dovetail interface, as shown in Figure 20. Cast iron has excellent built-in lubricating properties and, although the movement between the bed and slide is very slow, there is a need for a suitable method of adjustment to take up any wear that occurs. The common way of doing this is to use a gib strip. These metal strips sit on one side of a dovetail slide, such as on a cross-slide and are adjustable using several small set screws, incorporating locking nuts, to take up any slack so that the dovetail slide moves smoothly but without any play. Viewed from one end, the gib strip has a parallelogram cross-section with a series of indentations on one side which engage the adjusting screws and hold the gib as the slide moves. The working face of the gib should be polished to a shiny finish to provide accurate and smooth movement of the slide. Regular greasing is recommended for gib strips. More information on this is provided in Chapter 5.

Vices

Even the humble vice includes sliding parts and in the case of precision vices used, for example, to hold work in place on milling machines, they employ hardened and ground sliding surfaces usually of cast iron with enclosed lead screws. Providing the moving parts are kept clean, the graphite in the cast iron provides the necessary lubrication for the relatively infrequent movement of the jaws of a vice.

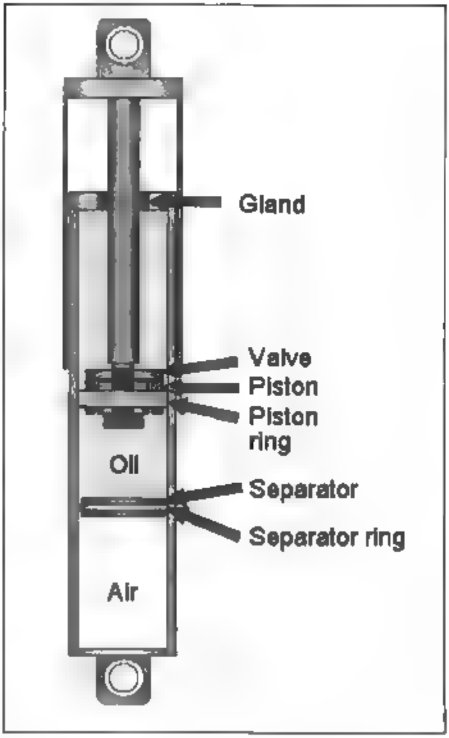

Figure 22. A cross-section through a shock-absorber. Both the piston and the separator rings as well as the gland require careful design and construction.

Shock-absorbers and oleos

Shock-absorbers are normally found only on wheeled or tracked vehicles, so that their use is limited to a few specialist modelling applications. Similarly, oleo legs are part of aircraft undercarriages and their use in models is limited to flying or museum-quality scale models of aircraft. The design of both items is similar and an example is shown in Figure 22.

As both the separator and the piston move, their rings are required to provide a high-

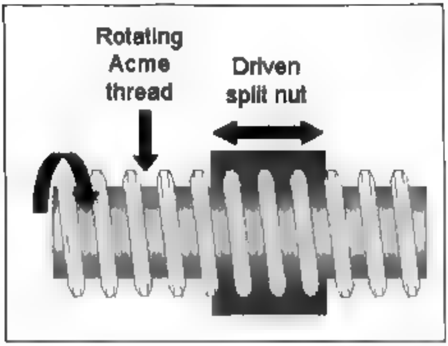

Figure 23. Cross-section through a lead screw with the popular Acme thread.

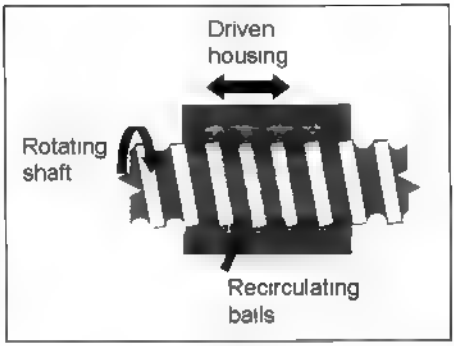

Figure 24. Cross-section through a low-friction ball screw.

quality seal to the walls of the cylinder, which contains oil on one side of the separator and compressed air on the other. In addition the piston rod has to pass through a gland at the top of the cylinder.

At model scales, both shock-absorbers and oleos are small components and require tight tolerances if they are to operate satisfactorily. Of course, the usual rules apply to the choice of dissimilar materials. Again, when building a shock-absorber or oleo leg, the cylinder should be honed to provide a suitable surface finish and the rings lapped to fit the cylinder. The gland also requires the usual choice of a suitable pair of materials; the rod normally being steel. And the gland must withstand the pressure within the cylinder when the assembly is fully compressed. One benefit, from a bearing point of view, is the use of oil on one side of the separator to provide the necessary lubrication.

Gas struts are built in a similar way but with a different valve arrangement and some model engineers may choose to repair or modify these struts to work as shock-absorbers. However, a word of warning, gas struts are pressurised and care is required to ensure the pressure has been released before undertaking any work on such items.

Linear-positioning devices

These devices are becoming increasingly popular in the home workshop to give precise control of the computer-controlled tables of machine tools. Apart from the motor and drive system that falls outside the scope of this book, the slides will either use a lead screw or a re-circulating ball screw.

Lead and ball screws

A lead screw is a means of converting rotational motion into linear motion. The rotation of a threaded rod, often with an Acme form of thread, moves a nut along its length. Care is needed in the selection of material for the nut to minimise the friction as it moves along what is almost always a steel shaft.

Lead screws are found on lathes and other machine tools driving the main slide. The lead screw needs to be kept clean and well lubricated to avoid wear and/or damage to itself and the split nut that is normally used

to drive the slide. Similar considerations apply to the cross-slides on lathes as well as the slides on milling machines and other machine tools.

Ball screws

A ball screw provides a larger degree of precision in linear motion than a similar lead screw. A threaded shaft provides a spiral raceway for a re-circulating ball assembly which acts as the nut As well as being able to apply or withstand high thrust loads they can do so with minimum internal friction. They are suitable for use in situations in which high accuracy is essential.

The design of ball screws, in contrast to conventional lead screws, is rather bulky, due to the minimum practical size of the mechanism that re-circulates the balls. To maintain the accuracy of ball screws, care is needed to avoid contamination with dirt or abrasive particles.

Ball screws reduce friction and can operate with some pre-load, effectively minimising backlash between the rotational input and linear output. Such systems are popular in CNC machine tools.

Unfortunately, ball screws can be back-driven due to their low internal friction, making them unsuitable for many hand-fed machine-tool applications. Though more expensive, a typical ball screw may be 90% efficient compared to the 50% efficiency of a similar Acme lead screw.

Linear-motion slides

A quick look at the slides of almost any filing cabinet will reveal a set of linear ball bearings. These items can readily be purchased, as can linear rolling bearings with monorail guidance, track-roller guidance, shaft guidance with linear ball bearings, flat-cage guidance, and linear-re-circulating roller or ball-bearing units. A typical system consists of a guide way/carriage unit, a linear bearing/shaft or a guide way with rollers or balls and flat cages between them.

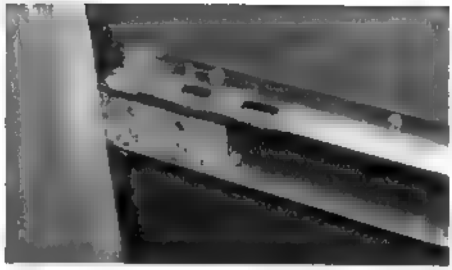

Figure 25. A typical linear-motion slide showing the balls that give the smooth-running action.

In general, linear roller bearings can be subjected to higher loads than equivalent ball-bearing solutions so that roller-based solutions are only really necessary for high loadings. As well as filing cabinets, these types of slides are increasingly found in the home, fitted to kitchen and bedroom drawers. Their weight-carrying capacity is excellent and little effort is required to open or close the drawers. When they fail, it is usually impossible to repair them and replacement becomes the only option, and then only if a similar or identical product can be obtained. Occasional lubrication with a smear of grease is recommended.

CHAPTER 4

Other types of bearing

Introduction

There are many different types of bearing that do not necessarily fall neatly into any of the major groupings described in the first three chapters of this book. Some can readily be made in the home workshop, but others, such as ceramic bearings, have to be bought.

Sintered bearings

The use of sintered metal, usually bronze but sometimes iron, is an excellent way of providing bearings that only require occasional lubrication. Sintering is a method of making objects, in this case bearings, from powdered metal by heating the material to a temperature below its melting point under high pressure until the particles adhere to each other. The resulting bearing material is porous and can then be impregnated with oil.

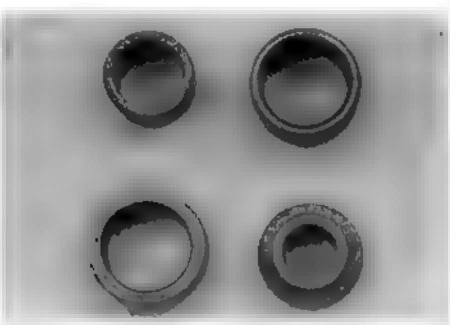

Figure 1. A selection of different sized and shaped sintered bearings.

The employment of sintered bearings is commonplace in the electric motors widely used to power machine tools. The overall loss of oil from a sintered bearing is low and these bearings will often last for an operating lifetime, but some are provided with a top-up oiling point or a wick feed so that they can be refilled. Oilite is the leading brand name for these bearings but most bearing manufacturers now offer sintered as well as their other types of bearings.

Re-sizing a sintered bearing is not to be recommended. Any attempt at lapping will result in the abrasive embedding itself in the bearing and thus rapidly damaging the shaft running in the bearing. Reaming tends to damage the bearing by tearing its surface. The only feasible way to increase the internal size of a sintered bearing is to cut it with an extremely sharp tool, taking care to avoid

Figure 2. A typical plummer block that can readily be purchased. Photo courtesy SKF.

tearing the material and closing its pores. It will then be necessary to re-oil the bearing before installing it.

Oilite bearings are a popular brand of sintered self-lubricating bearings made from an oil-retaining tin bronze, which provides a good balance between strength, wear resistance, conformability and durability in operation. These bearings are impregnated with high viscosity SAE 30 mineral oil containing anti-oxidant, anti-rust and de-foaming additives. Lower viscosity oil can be employed for cold temperatures, high speeds or light loads. The oil should be replenished after 1,000 hours use or annually. Bearings running submerged in oil or in oil-splash will not require replenishment.

Shafts should ideally be hardened, and with a smooth finish, and both the shaft and housing should have any sharp edges removed before fitting the bearing. Always use steady pressure to locate sintered bearings in place; never use hammer blows. And ensure the bearings are free of grit and dust. Wash them in oil if in doubt and re-oil bearings at least annually or if stored in an absorbent material. To prevent possible seizures with stainless steel or hard chromium-plated shafts, molybdenum disulphide should be added to the impregnation oil.

A shaft collar or shoulder can provide a degree of axial location where needed, and if moderate thrust is expected, the use of a thrust washer is recommended.

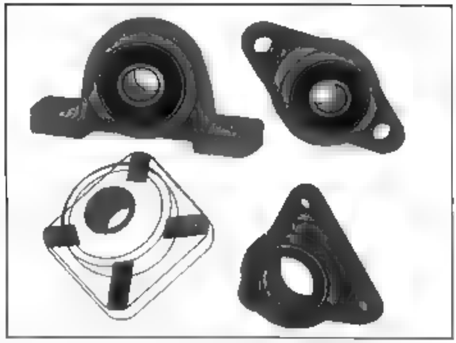

Figure 3. A selection of plummer-block designs; the classic design is top left.

Plummer or pillow blocks

Plummer blocks comprise a bearing housing that may be made of cast iron, cast or stainless steel, or bronze. Inside the block there is a fixed inner bearing that may be sintered, or a spherical seating to allow a non-rotating inner bearing to accommodate considerable shaft misalignments. Precise positioning and accurate alignment during installation are unnecessary. with this latter form of block

Manufacturers often offer alternative mountings such as two-, three- or four-bolt flange mountings that make their installation relatively straightforward. Several examples are shown in Figure 3. Some housings are also available with provision for re-greasing.

Split plummer-block bearing housings offer the significant advantage of easy installation of pre-assembled shafts. Once the bearing housing bases are attached to the base plate, the housing caps are placed in position and the attachment bolts tightened. Most split plummer-block bearing housings are intended for self-aligning ball, spherical roller or plain bearings.

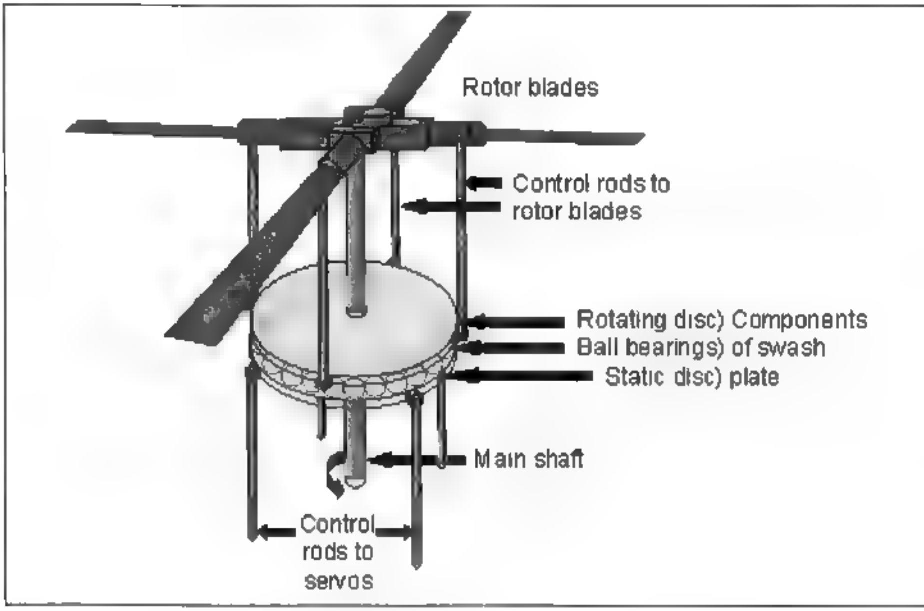

Figure 4. The swash plate with ball bearings fitted to a model helicopter. Each control rod requires a rod end (see Figure 8 on Page 59) fitted to its ends.

Swash plates

Helicopters and some auto-gyros employ swash plates to enable them to vary the angle of their rotor blades in order to provide cyclic and collective control of the main rotor and directional control of the tail rotor. The swash-plate assembly consists of two metal (in some models plastic) discs: the fixed and the rotating swash plates.

The rotating plate is fixed to and turns with the drive shaft and with the rotor blades. Links connect the rotating plate to the rotor blades allowing their angle to be altered as the angle of the rotating plate changes.

The servo-control rods connect to the fixed plate and allow its angle to change. The rotating plate moves in synchronisation with the fixed plate thus altering the pitch of the rotor blades as the cyclic and collective control servos move in response to the pilot's inputs.

Between the fixed and rotating swash plates there is a bearing interface that allows the rotating swash plate to spin above, but in contact with, the fixed swash plate. In all cases, care is needed in the selection of compatible materials for the two swash plates and the bearings between them. Steel swash plates with hardened steel balls between them provide a long-lasting solution but a pair of compatible materials may be employed to provide a sliding bearing, a source of lubrication is essential. Sometimes just a pair of plastic discs suffices.

Swash-plate pumps provide a first-class

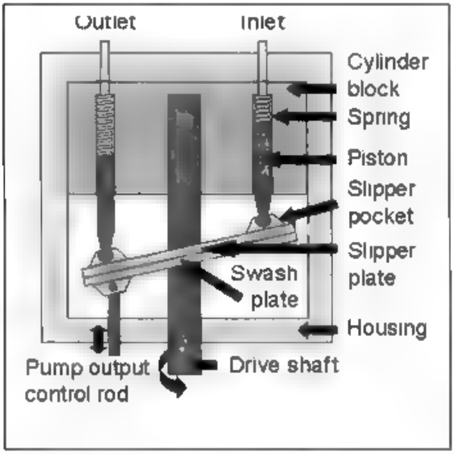

Figure 5. A swash-plate pump with slipper bearings.

way of varying pump output without changing the pump's drive speed. In this case, varying the angle of the swash plate changes the stroke of the pistons in their cylinders as the assembly rotates. The bearing requirements are similar to those of helicopter swash plates.

Slipper bearings

Awkward movement geometries demand innovative bearing solutions. In full-size life, slipper bearings are most commonly found in swash-plate and wobble-plate pumps. In swash-plate pumps, a rotating cylinder block contains a number of parallel pistons arranged in a circle around the cylinder axis. Springs press the balls formed at the ends of the pistons against slipper pockets attached to an angled slipper plate located at one end of the block. Each time the cylinder rotates, the pistons draw in fluid during half a revolution and expel it during the second half. Increasing the swash-plate angle in relation to the cylinder gives the pistons a longer stroke

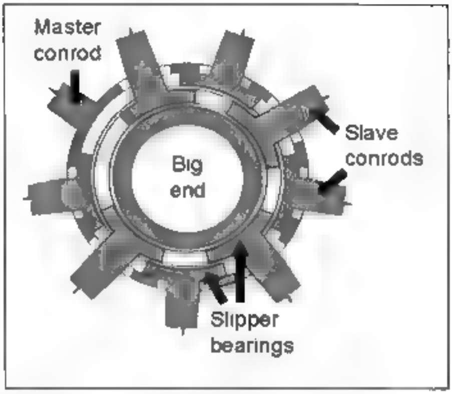

Figure 6. A slipper big end, as used, for example, in a scale Gnome engine.

and they transfer more fluid. The bearing arrangement at the swash-plate end of the pistons employs slipper bearings that are not dissimilar to spherical bearings. A wobble-plate pump works on similar principles, but in this case the cylinder block is stationary and the wobble plate (a form of swash plate) rotates. In both cases, care is essential to select pairs of compatible but different materials for the slipper-bearing and swash-plate surfaces.

Another type of slipper bearing is that occasionally used in multi-cylinder radial engines and was probably pioneered in the French Le Rhone rotary-aero engines at the beginning of the twentieth century. This type of slipper bearing involves slots in the master connecting rod to allow radial angular movement of the slave rods during operation of the engine. In this case, the big end of each slave connecting rod is in the form of a curved 'T' that slides in a series of curved slots around the big end of the master rod as shown in Figure 6. This type of bearing requires the slots of the master connecting rod to be made of a different material from the aluminium alloy

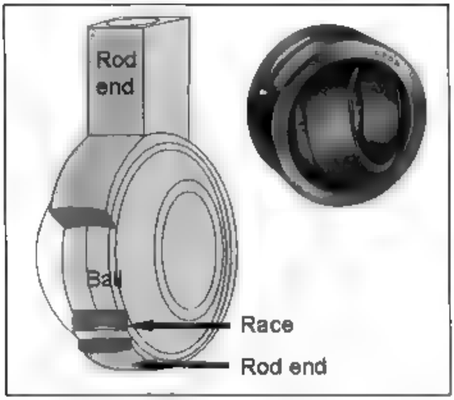

Figure 7. Left, a rod end; right, a spherical bearing showing the layout of the lubrication ways. Photo courtesy the Timken Company.

classically used to make all the connecting rods. Linings made of a copper-based alloy are one possible solution for the master connecting rod.

Spherical bearings and rod ends

The traditional ball and roller bearings described in Chapter 2 are designed to reduce friction and provide support for rotating assemblies. Rod-end and spherical bearings, on the other hand, are friction-type bearings designed to provide precise control of oscillating assemblies, while allowing for some axial misalignment. They may be used in some applications where there is a slow rotation rate but they are best employed in situations that require only a back-and-forth motion.

Spherical bearings are made to be inserted into user housings, while rod ends include the housing and means of connection to and adjustment of the length of a rod. In both cases, a one-piece steel race is swaged around a hardened ball that can be made of stainless

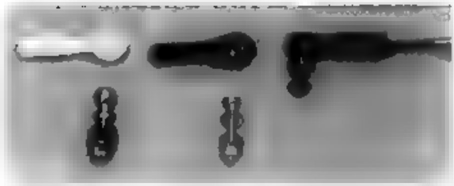

Figure 8. A selection of small plastic and brass rod ends of the type favoured by radio-control enthusiasts.

steel for applications where corrosion is likely to be an issue. The race may be drilled to allow for lubrication or the bearing may include a PTFE liner to avoid the need for permanent lubrication and to give a tight internal fit of the ball to the race. In the case of a rod end, the extremity is usually provided with a male or female thread; the ball may also carry an internal thread. Typical configurations are shown in Figure 7.

Spherical bearings and rod ends come in a wide range of sizes and are manufactured from several different materials. Their main use is for operating push rods. Model engineers use them in scale cars and other types of vehicle for the track rods, and in radio-controlled helicopters for the links to the rotor head and to the tail rotor. Full-size applications abound but they are most commonly found when working on cars.

A particular form of rod end is the ball joint used on some radio-controlled models, particularly cars and helicopters, to connect the servos to the parts to be moved. These are shown in Figure 8 and are very small, generally made of a tough type of plastic either with a plastic cup that clips over a brass ball or with a metal ball moulded in that can be bolted to the servo arm. They are maintenance-free and do not require any lubrication.

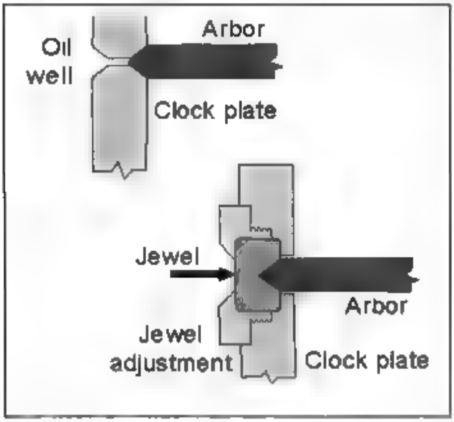

Figure 9. A clockplate with a brass-coned bearing (top) and a jewelled one (bottom).

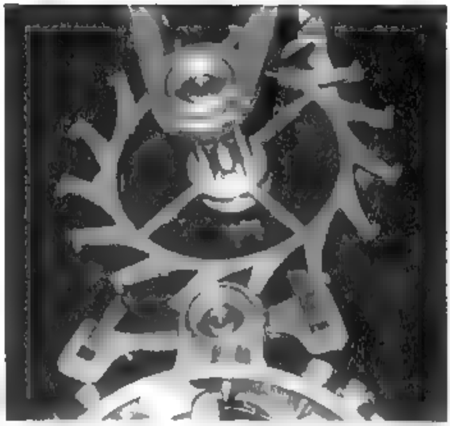

Figure 10. Making long-lasting clock bearings requires a high degree of skill.

Coned-pivot and jewelled bearings

The coned bearing is designed to take both axial and radial loads. It is often employed by clock-makers, particularly when a balance wheel is used and Figure 9 shows two possible configurations: using a brass clock plate with an oil well and an adjustable jewelled alternative.

In the case of a clock, the bearings are normally part of the brass clock plates and are drilled and countersunk to a coned shape on each side, using a tapered reamer and a finishing broach. The inner cone provides the bearing surface for the clock arbor while the outer cone acts as an oil well to lubricate the bearing. The steel arbors which carry the clock's brass gears, with their pivots at each end, must be burnished and polished to a mirror finish to reduce friction and wear rate. For faster moving parts, such as balance wheels, it is common to find the steel shaft running in jewelled bearings, normally made from ruby but sometimes sapphire or garnet, with a cone-shaped socket for the arbor.

Coned bearings are also found in precision mechanical instruments, such as dial gauges, and, of course, every time a coned centre is used in a lathe tailstock. This type of bearing is not ideal for continuous rotation and is better suited to a shaft that is rocking back and forth. Despite this, it is the type of bearing used whenever work is mounted between centres on a lathe, although for preference, a rotating coned centre with a ball bearing should be used in the tailstock.

Cone-bearing lathes

The lathes used by watch-makers almost invariably incorporate coned bearings, as do a few other older lathes. Part of the spindle resembles a truncated cone with bearings to match. During manufacture, the spindles are usually carefully ground to the required taper after hardening. Conical bearings are fitted to the cast-iron headstock and then both spindle and bearings are lapped to provide a perfect fit.

The terms 'hard' or 'soft' bearings indi-

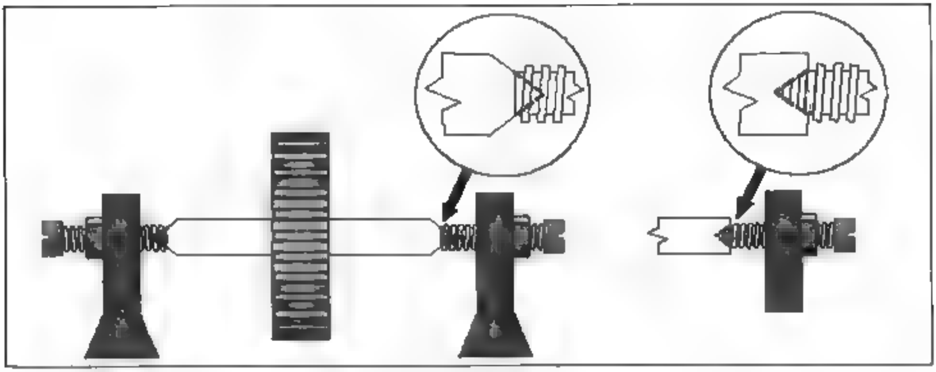

Figure 11. Left, a pair of coned-pivot bearings with male cones on the shaft; right, with a female cone within the end of the shaft.

cate whether the inserts in the headstock are hardened and ground steel or machined bronze/phosphor bronze. Bronze bearings will seat faster and are more tolerant of grit than steel bearings, as odd particles of dirt or swarf will bed into a bronze bearing rather than rotating and scoring the spindle. Also bearings made from bronze may last as long as steel ones. Well-adjusted cone bearings provide a similar level of accuracy to quality plain or ball bearings.

Lateral turning of items in a cone lathe tends to try and force the spindle out of the bearing. As a result the spindle is contacting only the part of the bearing diametrically opposite the turning tool and after a time this will result in an oval-shaped bearing; a significant problem with this type of bearing.

For normal use in watch-making, the bearings should be adjusted to be as tight as feasible without the lathe seizing in use. Prolonged or high-speed use requires the spindle to have a marginally looser fit, since any significant heat generated could cause the spindle to lengthen and the bearings to seize.

To adjust the bearings after dismantling and cleaning the lathe, start by coating the bearings and the spindle cones with light machine oil. Carefully re-assemble the spindle and tighten the rear cone of the spindle assembly until a slight resistance is felt as the spindle is turned by hand. Wait a short time to ensure any excess oil has drained from the bearing. Re-adjust if necessary and lock the bearing in position, making sure that the correct adjustment is not lost during the tightening process. It is also sensible to check for spindle end-play using a dial gauge.

A rather different form of truncated-cone bearing is shown on the illustration of the lathe in Figure 13.

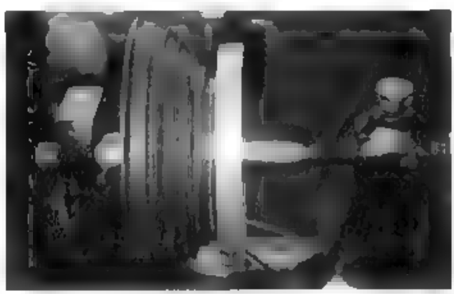

Figure 12. A coned-bearing lathe showing the drive pulleys.

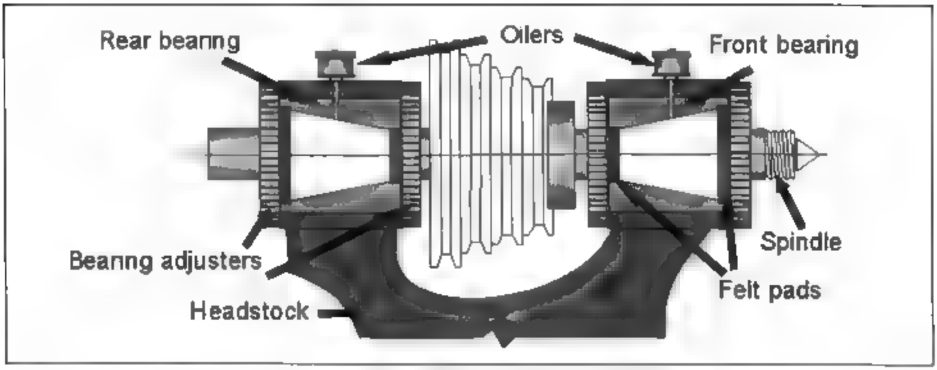

Figure 13. Coned bearings in the headstock of a lathe.

Plastic ball bearings

Plastic or polymer ball bearings can be made from a variety of materials, such as acetal resin or other plastic combinations, the materials chosen depending on the particular requirement. These bearings consist of polymer rings with balls made of stainless steel, glass, polymer or a range of other materials, the balls being contained in a polymer cage. The bearings can be supplied with polymer shields or rubber seals and may or may not be supplied with a flange.

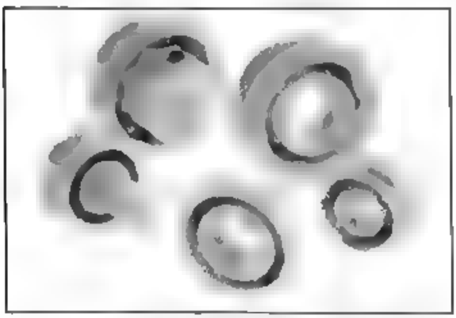

Figure 14. A selection of plastic ball bearings. Photo courtesy SKF

Polymer bearings give several benefits. Most steel-bearing failures are caused by corrosion, a factor that does not affect polymer bearings; they can safely be used in sea water. As there is no metal-to-metal contact, they provide very low levels of friction so that heat dissipation is less crucial. Also they run more freely and have lower inertia due to the tiny friction levels between the races and the balls. Other benefits include their light weight, the fact that they require no lubrication and their quiet running.

They provide high resistance to wear and fatigue as they inherently dampen any vibrations. They also absorb shock loads better than metal due to their elastic nature, without the risk of the failure mode of steel ball bearings, where the balls can dent the raceway. However, their load-bearing and maximum speed ratings are much lower than for all-steel bearings and operating temperatures must not exceed around 90°C.

They are only 20% of the weight of equivalent steel ball bearings, have a high strength-to-weight ratio and excellent lifetime dimensional stability due to the low creep tendency of the chosen polymers. However,

plastic bearings are not manufactured to the same precise tolerances as steel ones; the typical inner and outer race tolerances on plastic bearings are +/-0.05mm (0.002").

Plastic ball bearings are completely non magnetic if they are fitted with polymer, glass or non-magnetic stainless balls. As mentioned in Chapter 2, plastics may also used to make the cages for conventional ball bearings.

Ceramic ball bearings

Ceramic ball bearings are not built of the sort of ceramics used to make household china! They are a relatively recent development and their rings and balls are made from a ceramic material such as silicon nitride ($Si3N4$) or zirconium oxide ($ZrO2$), the former providing a higher load and speed capability. They often use a PTFE or PEEK cage. Hybrid ceramic ball bearings, on the other hand, employ steel inner and outer rings (or stainless steel where corrosion or heat resistance is important) with ceramic balls in place of steel ones. In addition to a full range of ceramic ball bearings, many different types of ceramic roller and needle bearings are also available.

Ceramic ball bearings can be used in a number of applications where standard steel ball bearings are unsuitable. Ceramic bearings are lighter (only 60% of the weight of steel equivalents) and, as the ceramic material is twice as hard as the steel in ball bearings, they have smoother surfaces and are more wear-resistant. The result is improved system rigidity and superior overall accuracy. They are better at conducting away heat than steel ball bearings, are significantly more corrosion resistant and require essentially minimal lubrication. In addition, they are able to operate over a wider temperature range (to over 950°C), are non

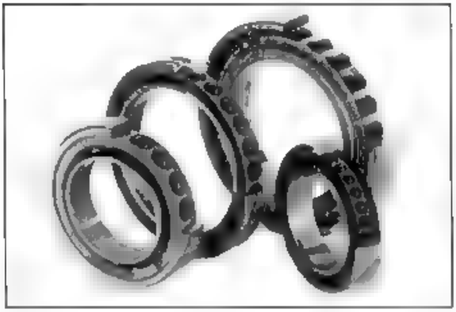

Figure 15. Ceramic ball and roller bearings look very similar to conventional steel ones. Photo courtesy Schaeffler UK.

magnetic and do not conduct electricity.

The lower weight of the ceramic balls reduces centrifugal loading so that ceramic bearings can operate significantly faster than conventional bearings and waste less energy maintaining the speed. In addition, the balls exert less outward force against the outer race groove as the bearing turns. This in turn reduces the friction and rolling resistance within the bearing.

As with standard steel ball bearings, ceramic ones come in a range of different types: open, with rubber seals or steel shields, with a snap ring groove, with a flange, as self-aligning ball bearings, as single-row angular-contact ball bearings, and as single- or double-direction thrust-ball bearings.

Ceramic bearings have little place in the construction of steam-powered models as they offer few benefits in low-speed models. However, in the construction of model gas turbines, where rotational speeds can approach 200,000 rpm and the gap between the turbine and its housing is minimal, their use is essential. In this application, a mist of a fuel/oil mix passes through the full-complement cageless bearings without shields or seals, both to cool and

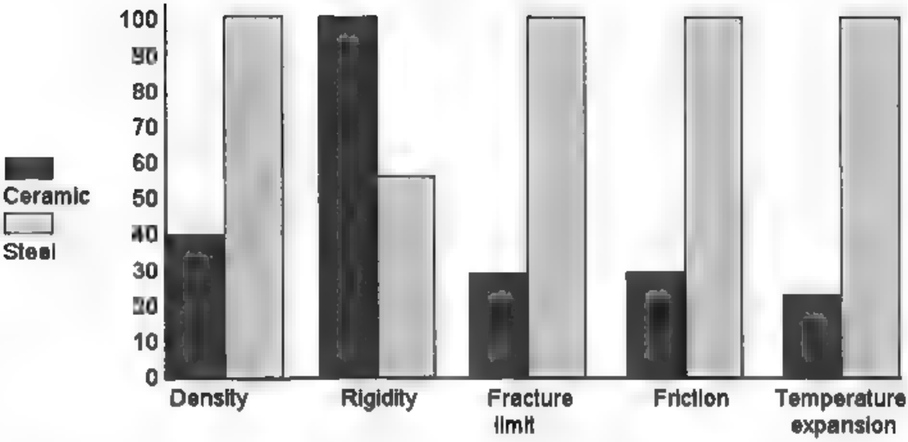

Figure 16. A comparison of the relative properties of steel and the ceramics used in bearings.

to lubricate them. However, at those speeds, bearing life is not long and regular replacement is needed.

With the small radial tolerance between the turbine and its casing, any bearings will need to be carefully pre-loaded and the popular solution to this requirement in home-build gas turbines is to use spring pre-loading to some tens of newtons (1N = 2.25 lbf).

The use of ceramic bearings is likely to increase in fast-revving model internal-combustion engines as well as four-strokes where their resistance to the damaging effects of the corrosive by-products of the combustion of nitromethane in the fuel is a distinct advantage. Full-size areas where model engineers may come across ceramic bearings include bicycles, where their low friction properties have made them popular as a way of increasing speed for the same input effort by the cyclist, as well as in certain sensitive instruments.

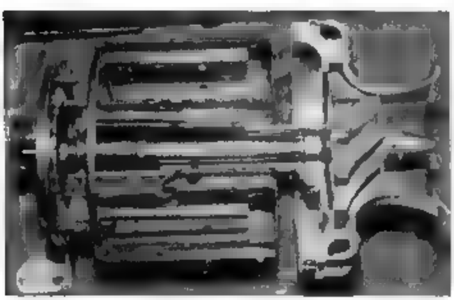

Figure 17. A model gas turbine, such as the popular home-build KJ66, places the highest demands on ceramic ball bearings.

Wankel engines and vane pumps

A completely different type of bearing problem occurs in Wankel engines, where the high temperatures of combustion exacerbate the problem. The bearings for the rotating rotor are relatively straightforward but the sliding movement of the seals between the rotor and its housing requires careful design, the use of appropriate materials and precise construction.

The Wankel is a rotary four-stroke engine where the rotor housing is oval-shaped with a waist (an epitrochoid) and is usually made

from aluminium alloy, chrome-plated on the inside walls to reduce wear on the seals. The rotary 'piston' is a triangular in shape with curved edges, made from cast iron or aluminium alloy, and combustion occurs in the space between pairs of apexes, providing three rotating 'cylinders' for each single rotor. A fixed gear mounted on the main shaft meshes with a ring gear inside the rotor to provide the correct path for the tips of the rotor as it turns. Because the Wankel is a rotary engine, in general, the maximum revs limit is significantly higher than in an equivalent reciprocating engine.

At each apex, or tip, of the rotor, there is a metal blade that forms the apex seal with the outer edge of the combustion chamber. There are also metal ring seals on each side of the rotor to stop leakage between the sides of the rotor and the walls of the combustion chamber. The principal 'bearing' problem lies in the three seals between the corners of the rotor and the cylinder walls, particularly as the variation in temperature of the walls ranges from relatively cold at the intake zone to very hot in the combustion zone. This gives rise to unequal thermal expansion of the rotor housing. The seals are normally made from a high-temperature alloy steel containing both chromium and molybdenum (more recently ceramic materials have been used with success) and centrifugal force presses the three tip seals against the housing. To preserve the rotor seals, it is normal to add a small quantity of oil to the fuel used.

In cooler running elliptical-vane and sliding-vane pumps, the vanes have to move up and down in slots in the rotor, as well as providing a seal against the pump housing. Thus they need to be carefully fitted into their slots and lapped against the pump casing. However, high temperature is not a problem and these

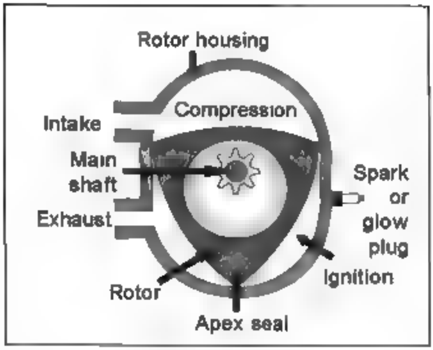

Figure 18. The internal construction of a Wankel engine showing three apex seals.

types of pump are used to move many liquids with self-lubricating properties.

Rotary valves

While rotary valves have only rarely been used in steam engines they have, to a large extent, been the holy grail of internal-combustion engine designers. There is one notable exception which is the rotary intake valve found in many single-cylinder two-stroke engines. Perhaps the reason for the success of these valves is that they are not exposed to the heat of the products of combustion in the engine. They merely allow a fresh charge

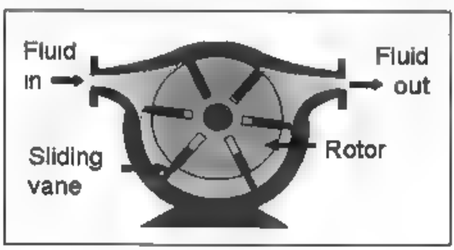

Figure 19. The sliding-vane pump and the elliptical-vane pump are very similar and require the same types of bearing.

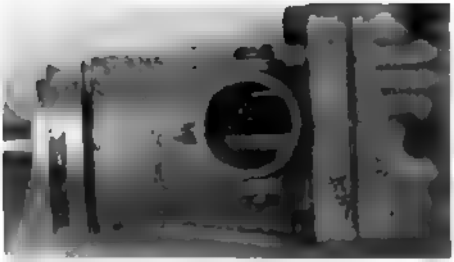

Figure 20. The intake valve of a well-used two-stroke model aero-engine shown in the half-open position.

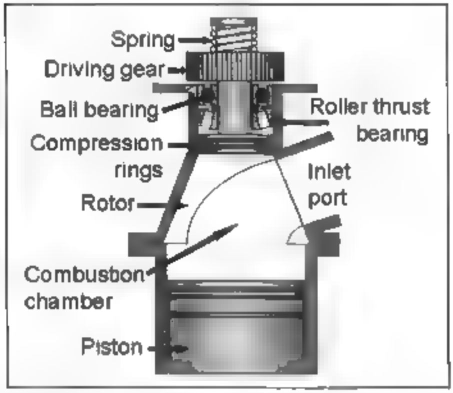

Figure 21. An Aspin rotary valve with the inlet port open and the piston descending.

of the fuel/air mixture to be drawn into the crankcase of the engine through a drilling in the crankshaft. While the crankshaft itself may run in a plain or ball bearing, the valve itself is part of the steel crankshaft running in the usual copper alloy insert. And the fact that these engines run on a fuel/oil mixture reduces lubrication problems of the bearing surface to a minimum. A typical example of one of these inlet valves is shown in Figure 20.

Rotary internal-combustion engine valves

Over the past century, there have been many different designs of rotary valves for internal-combustion engines, such as the Aspin, Cross, Froede, Mellors, Norton and Lotus, named after their designer or, in the last two cases, the company that developed them. Their main problems lie in sealing against the pressure and the products of combustion, the differential heating, and maintaining lubrication without excessive oil consumption.

The Aspin valve, shown in Figure 21, has the valve mounted at right angles to the crankshaft, directly above the cylinder. The tapered rotor in full-size engines was originally made from case-hardened nickel steel turning in an aluminium-bronze housing. Aspin-valved engines tend to suffer either from high oil consumption or, predictably, frequent valve seizure. The use of a ball bearing and roller-thrust bearing allows the rotor to turn readily but the seal between the rotor and its housing still presents something of a problem in model sizes, not to mention the need for compression rings to provide protection for the bearings.

The Cross rotary valve is mounted parallel to the crankshaft and offers a better solution. It also suffers from high oil consumption and plug fouling but without the high risk of valve seizure. The valve layout is shown in Figure 22.

Carburettors

Although carburettors have largely disappeared from modern full-size engines, they are widely used by modellers constructing both free-lance and scale models of internal-combustion engines. And carburettors do have built-in moving parts and thus several bearings.

The rotating-barrel carburettor is the most common type of carburettor design used

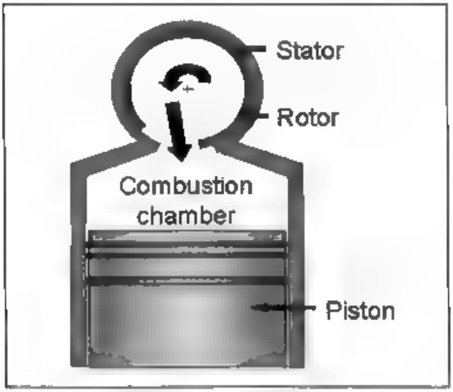

Figure 22 A Cross rotary valve with the inlet port opening and the piston descending.

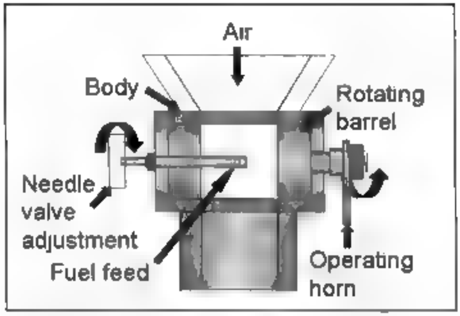

Figure 23. An internal view of a rotating-barrel carburettor showing the moving parts.

in model internal-combustion engines. It includes a number of revolving parts. The body will normally be made from aluminium alloy; invariably if it is part of an aero-engine. This means that the rotating barrel can be fashioned from steel, with a brass spray bar and tapered-steel needle valve to allow adjustment of the fuel/air ratio by feeding metered fuel into the airflow.

This choice of materials ensures free movement between all the rotating parts, none of which turns at any significant speed. All parts move through comparatively small angles and only the needle valve turns a full 360°, usually several complete revolutions from fully closed to wide open. Thus none of the bearings is highly stressed.

Providing the fuel contains a percentage of oil (this is normal for glow-plug engines, diesels and two-stroke petrol engines), all the carburettor parts will automatically be lubricated. However, for four-stroke petrol engines an occasional oiling of the moving parts is essential.

Rotary steam valves

While rotary valves are not common in steam engines, there are full-size prototypes that have used them and some model engineers have experimented with several different rotary-valve layouts and published designs for working models. The most common form of steam valve follows the Cross layout shown in Figure 22, but without the heat, pressure and products of combustion problems inherent in any internal-combustion engine rotary valve. Furthermore, the speed of rotation is considerably lower and the oil added to the steam provides sufficient lubrication for the pistons, cylinders and the valves.

Sleeve valves

Some of the more complex designs of reciprocating internal-combustion engine use sleeve valves. Model engineers most likely to come across sleeve valves are those building scale models of World War II aero-engines, such as the Napier Sabre or Bristol Centaurus. In full-size service, they were replaced by the jet and were always difficult to manufacture. They were unpopular due to a tendency to seize because of a lack of

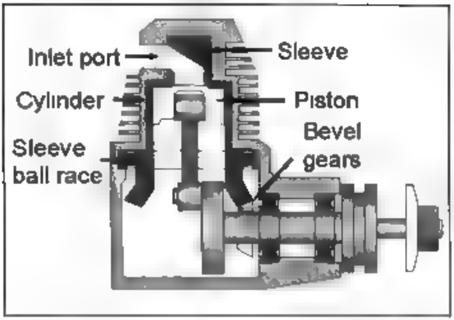

Figure 24. The piston/sleeve/cylinder layout of a sleeve-valve engine. The exhaust and inlet ports are offset by 90°.

lubrication. A sleeve valve consists of one (or sometimes more) machined sleeves that fit within a piston-engine's cylinders. The sleeves are designed to rotate and/or move vertically so that their openings align with the cylinder's inlet and exhaust ports at the appropriate times.

The benefit of using a sleeve valve is that it allows very large port openings and an all but perfect combustion-chamber shape to increased volumetric efficiency. In addition, the power-to-weight ratio is better and complexity is reduced when compared with poppet-valve engines. Its major disadvantage is that perfect sealing of the combustion chamber is difficult and lubrication of the piston/sleeve and sleeve/cylinder interfaces is tricky.

RCV, a UK company, produces a range of four-stroke rotary sleeve-valve engines, ranging from just under 10cc to a little over 20cc displacement, for use in radio-controlled model aircraft. They all employ a rotating sleeve valve. The layout is shown in Figure 24 and a photograph of a sectioned engine in Figure 25.

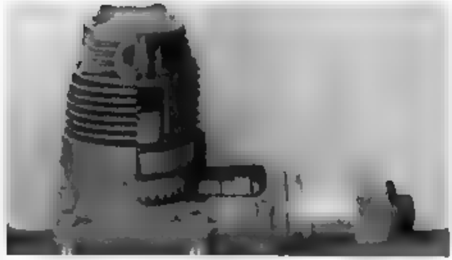

Figure 25. A cut-away version of the RCV sleeve-valve model aero-engine showing the bevel gear that rotates the sleeve.

Pivot or knife-edge bearings

Pivot, or knife-edge bearings are often found in sensitive balance scales where a horizontal beam is set on a fulcrum comprising a sharp V-shaped pivot seated in a shallow V-shaped bearing. This kind of set-up reduces friction to an absolute minimum. The pivot should have an included angle of 90° and should be made from hardened and polished tool steel, while the V-bearing should have an angle of around 150° and should also be made of hardened steel.

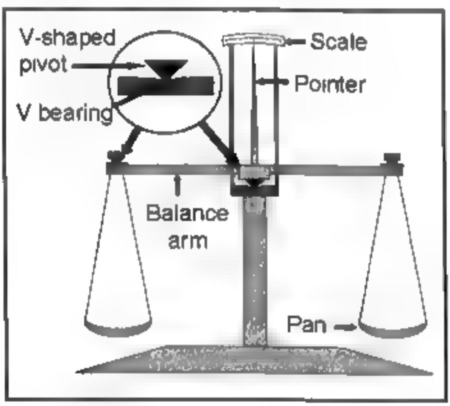

Figure 26. A balance scale using three knife-edge bearings.

CHAPTER 5

Lubrication and seals

Introduction

The useful life of any bearing depends to a great extent on its proper lubrication. This is particularly true of bearings operating in dirty or moist conditions or extremes of temperature. Lubricants help to remove heat, provide protection from corrosion, reduce friction and prevent premature bearing damage. Whether oil or grease is used depends on operating conditions, including the regularity of maintenance. Some bearings are either pre-lubricated for life or are made from plastic materials that require no lubrication.

There are four different types of lubricant available: animal, vegetable, mineral and synthetic. Animal and vegetable products were the original choice for lubricating early bearings and machines. The development of the petroleum industry led to the production of mineral oils and greases. In the last century, new oils were synthesised, often using a silicone base that improved a number of desirable characteristics that were not available in any of the other three types of lubricant.

Adequate lubrication that maintains a film of oil between the two parts of a bearing is the key to the life of any plain bearing. As a shaft rotates, an area of high-pressure oil builds up in the direction of the load and keeps the shaft and bearing apart. Any misalignment of the bearings or variation in the direction

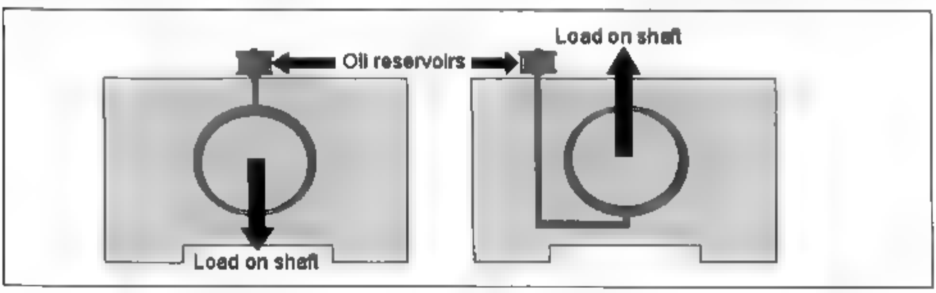

Figure 1. Oil should, if possible, be fed to the part of the bearing where the pressure is lowest.

of the load, as occurs for example in a lathe headstock, may cause penetration of the oil film and metal-to-metal contact. This leads to over-heating, scoring of the bearing surfaces and eventually permanent damage or even seizure of the bearing. In the same way, a poorly finished bearing may result in localised penetration of the oil film and the production of particles of the metals as a result of damage to the bearing materials. Similar problems occur if dust or dirt is able to enter a bearing. It is worth noting that the use of softer bearing materials, such as Babbitt metal or bronze, will allow particles of metal or dirt to embed in their surfaces, thus reducing the chances of badly damaging the bearing.

When rolling bearings work in a clean environment, the main cause of damage and eventual failure is fatigue of the surfaces where rolling contact occurs. However, when dirt enters the bearing it often causes damage, which can shorten bearing life. If dirt or metallic debris from some component in the model contaminates the lubricant, wear may become the major cause of bearing damage, and if bearing wear becomes significant, the critical bearing dimensions will change. While this may not be crucial in a model, it could adversely affect the operation of a machine tool such as a lathe.

Until relatively recently, all bearings have required lubrication by either oil or grease, with provision made for such lubrication, often by manual oiling, oil feeds from tanks or sumps, or grease nipples. More recently, the development of the sintered bearing has dramatically reduced the need for frequent lubrication while some ball and roller bearings are lubricated for life and many plastic bearing require no oil or grease whatsoever.

The five main reasons metal bearings require lubrication are to:

1. Reduce friction and wear by providing a film of sufficient strength and thickness to support the load and, in the case of rolling bearings, to separate the balls or rollers from the races and cages, preventing metal-to-metal contact.
2. Remove heat from the bearing.
3. Prevent corrosion of the various elements of the bearings.
4. Provide a barrier to contaminants.
5. In the case of ball and roller bearings, reduce rolling resistance due to the rolling elements and races deforming under load by providing a lubricant film between the surfaces.

Thus, most modelling applications need some thought to be given to lubrication needs despite the fact that operating conditions are not always severe.

Choice of lubricant

The wide range of bearing types and operating conditions prevents simply choosing a best lubricant. It is also important to avoid mixing different types of lubricant together. If designing a model or full-size machine, first decide whether oil or grease is best for the particular application. The advantages of oil and grease are outlined in Table 1. When very

Oil	Grease
Carries heat away from bearings	Eases seal design and acts as a sealant
Carries away moisture and dirt	Allows pre-greased sealed/shielded bearings
Easily controlled lubrication	Requires less frequent lubrication

Table 1. The relative advantages of oil and grease as lubricants.

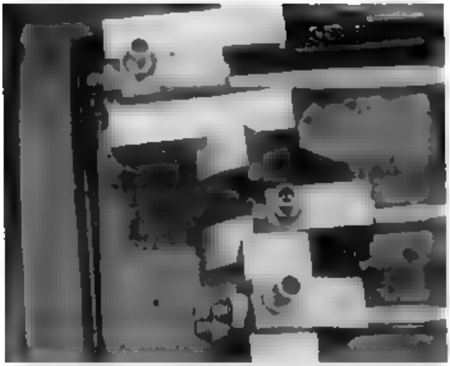

Figure 2. Oiling points on the con-rod bearings of a stationary horizontal steam engine.

Figure 3. A grease nipple fitted to a plummer block. Photo courtesy the Timken Company.

low torque levels are needed, oil is the preferred choice. The application of grease lasts considerably longer than oil and is often expected to endure for the total working life of many bearings. When heat must be carried away from the bearing, oil is essential and is almost invariably the choice for very high-speed applications.

The selection of a suitable lubricant is important to any bearing. For plain bearings, oil is the preferred choice and the required viscosity of the oil depends on three main factors: the temperature, which directly affects the viscosity, the load on the bearing and the speed at which it turns. In essence, heavily loaded slow-speed bearings require a heavy grade of oil but as speed increases and the load reduces a lighter oil is preferable. Fortunately, today's multi-grade oils are relatively thin when cold but act like a heavy-grade oil when hot.

The choice of lubricant also affects the life of the bearing, its maximum speed, the torque needed to turn it, the noise it generates, the creation of heat and the prevention of corrosion, as well as grease migration and out-gassing. The chosen lubricant also impacts on the performance of any ball or roller bearing. In some instances, however, rolling bearings may be purchased pre-lubricated with grease and sealed for life.

Today's bearing designers and manufacturers are making rolling bearings for use in modern industrial plant and machinery, where bearing reliability is a key factor, rather than for use in engineering models and home-workshop machine tools. One of the major contributing factors to achieving this reliability is proper lubrication, and some applications, such as lathes and milling machines, need bearings that maintain their performance over a long life.

Bearings require a very thin film of lubricant, which has to be maintained to ensure reliable operation throughout their design life. The ways of ensuring this are to use the right lubricant, apply it correctly, and keep it clean. Neglecting any of these will increase the risk of premature bearing failure. There are a few areas where the presence of oil is contra-indicated, such as close to commutators of electric motors. In such cases, graphite-impregnated bushes, sealed rolling or plastic bearings may be preferred.

The choice of lubricant (oil or grease), de-

pends on the application, though recently, the use of plastics to make bearing housings means the lubricant may need to be chosen with care to avoid adverse effects on the plastic. Some solid dry-film lubricants also exist but are generally limited to moderate speed and extremely low loads.

Additives are normally incorporated in both oils and greases to improve their performance. They increase lubricant life, prevent oxidation and maintain cleanliness, minimise friction, improve corrosion resistance, reduce wear and decrease viscosity changes with temperature. Inorganic additives, such as molybdenum disulphide, graphite and zinc oxide, may be included in lubricants and model engineers can take advantage of their benefits.

However, it should be remembered that the characteristics of similar oils and greases vary from one manufacturer to another. The selection of a bearing lubricant needs to suit the operating conditions and limitations of the application. The most significant factors in choosing a lubricant are:

1. Its viscosity at the bearing operating temperature.
2. Its allowable operating temperature range.
3. The normal and maximum rpm of the bearing.

While grease lubrication tends to be much simpler to implement than oil, there are still many places where the use of oil is either essential or a far better choice, particularly on some scale models.

Oils

Some of the benefits of oil lubrication are:

1. Oil is better than grease for high speeds, elevated temperatures and low-torque applications. It can be cooled to reduce bearing temperature.
2. Oil is easier to handle than grease and it is easier to control the amount of lubricant reaching the bearing, but is harder to retain oil in the bearing.
3. Being a liquid, oil can be fed to bearings in a variety of ways.

Which oil?

The major oil companies offer many different products for a wide range of applications, such as vehicle, aviation and industrial use. Oils may be classed as petroleum-based (refined from crude oil), vegetable-based (obtained from plants) or synthetic (made by chemical synthesis). Petroleum oils are suitable for a range of applications. They may be used in diesel, petrol or methanol-fuelled two- or four-stroke engines or gearboxes and can be single viscosity or multi-grade; with or without additives. Vegetable oil, and in particular castor oil, is often used in miniature internal-combustion engines while synthetic oils cover a broad range of products that are less prone to oxidation and can operate at extreme hot or cold temperatures. Tallow, an animal by-product is used as an additive to steam oil. Physical properties tend to vary between oil types requiring care when choosing any particular oil.

The selection of oil viscosity for any particular bearing application depends on several factors: load, speed, available torque, bearing setting, type of oil, environmental factors and particularly temperature as viscosity varies inversely with temperature. High-viscosity oil is ideal for low-speed or high-ambient temperature applications. Low-viscosity oil is preferred for high-speed or low-ambient temperature as well as low available torque applications. Working in order of increasing viscosity, there is clock oil, 3-in-1 oil, plain or

multi-grade engine oil and gearbox oil

Any water in lubricating oil has a detrimental influence on bearing life and as little as 0.1% can reduce bearing life tenfold. The use of water-displacing oils can help at the end of a running session where water from condensation is likely to be a problem. There are also preservative oils, used to protect the bearing surfaces when machine tools are stored.

In a few specialist applications, such as model jet engines, the high speeds and temperatures at which their bearings operate, combined with the need for high precision and reliability, mean that choosing a suitable bearing lubricant is particularly critical to successful operation in these tough environmental conditions.

Another area which requires special consideration is the lubrication of steam-engine cylinders and valves. In addition to noting the expected maximum temperature and pressure of the steam, and whether it is saturated or super-heated, it is essential to use an oil that is thermally stable at the high temperatures experienced and sufficiently viscous to deposit a film of oil (usually an oil emulsion) on the rubbing surfaces without leaving carbon or other deposits, particularly under dry-steam conditions. The oil film must also survive the washing effect caused by the moisture in the steam.

The lubrication of pistons and rings in the cylinders of miniature reciprocating internal-combustion engines is mostly dealt with by adding oil to the fuel to provide lubrication of both the oscillating and the rotating parts, though a few more complex engines may employ oil tanks/sumps and pumps. In two areas of interest to model engineers, high-speed spindles and model gas turbines, oil can be supplied continuously to provide cooling as well as lubrication. At the other extreme are clock, and scientific instrument bearings, where very low values of starting and running torque are essential. These applications require only a single drop of oil.

Finally, many modellers enjoy replicating the complexities of the lubricating systems found in Victorian and twentieth-century prototypes. Since, by definition, the majority of models built are considerably smaller than the original prototypes, it is preferable to use lower viscosity oils to try and compensate for scale effects. Some specialist oils for use on steam engines, gas turbines and clocks are described later in this chapter.

Greases

The original greases were animal by-products such as lard: rendered fat obtained from pigs. Modern greases are made by dispersing a thickening agent in a liquid lubricant. There are many different types and each individual product has its own defined properties. Synthetic lubricating fluids are used with conventional thickeners or additives to enable greases to operate over very wide temperature ranges (-70°C to +280°C). Greases are by far the simplest and most widely used rolling-bearing lubricants and their successful employment depends on the choice of grease and the bearing's application, installation and operating environment. Modern greases can provide lifetime lubrication for suitably designed sealed ball bearings.

Their main advantage of grease over oil is the ability to pre-lubricate bearings at manufacture, eliminating the need for an external lubrication system. Besides simplicity, grease lubrication also requires less maintenance and has less stringent sealing requirements than oil systems. Grease tends to remain in proximity to bearing components, metering its oil content to operating surfaces as need-

ed. However, grease does not conduct heat away from a bearing as well as oil. In addition, grease may increase both initial starting and running torque. Also to avoid overheating, speed limits for greases are mostly lower than those for oils.

Grease lubrication is generally applicable for low-to-moderate speeds that keep within the grease temperature limits. Grease is easily confined in a housing, and improves the efficiency of mechanical seals, giving improved bearing protection. And the bearing enclosure and seal design are simplified. Also successful are integrally-sealed, pre-lubricated bearings that are packed with chemically- and mechanically-stable grease to provide long bearing life. These shielded and sealed bearings are ideal in applications where:

1. Grease might cause problems to other parts of the model or machine.
2. Space restrictions preclude using a grease-filled housing.
3. Housings cannot be kept free from dirt, water or other contamination.
4. Re-lubrication is not possible.

The two main factors determining the need for re-greasing are the operating temperature and the efficiency of the seals. The higher the running temperature, the more often the grease will need replenishing as grease life is typically reduced by around half for every 10°C temperature rise. Any leakage will also require regular replacement.

Which grease?

Conventionally, greases used in bearing applications are petroleum-based and thickened to the desired consistency by a metallic soap. There are many soap types involving sodium, calcium, lithium, or aluminium. Non-soap thickeners are also used in some products. Calcium greases have good water resistance. Most sodium greases have good stability and will operate at higher temperatures, but absorb water and so cannot be used where moisture is present. Lithium, calcium-complex and aluminium-complex greases, known as multi-purpose greases,

Castrol CL Grease Soft calcium-based grease for chassis lubrication, swivels and spring shackles. Resistant to salt-water spray.

Castrol Graphite Grease Waterproof graphited grease ideal for road leaf springs where metal-to-metal contact is best avoided. Also for use on brake cables.

Castrol Heavy Grease A heavy calcium-based grease with excellent anti-corrosion properties, with particular application to rear wheel bearings on early MG cars.

Castrol LM Grease Wheel-bearing and multi-purpose high-melting-point lithium grease.

Castrol Moly Grease Molybdenum grease for use on kingpins and shackles. Also used in engine re-assembly on items like main and camshaft bearings.

Castrol PH Grease White, tacky, water-resistant grease. Recommended for inaccessible applications such as brake shoes, gear linkages and wheel splines.

Castrol Red Rubber Grease Special rubber-compatible grease for use on hydraulic brake and clutch components where hardening or swelling must be avoided.

Castrol Water Pump Grease Stiff, smooth lime-based grease with excellent water resistance ensuring unbeatable sealing properties in water pumps.

Castrol MDX Grease Molybdenum grease with high-load characteristics and excellent adhesion to metals. Ideal for steering rack and steering box lubrication.

Table 2. Just one company's list of automotive greases detailing their applications.

combine high-temperature properties with water resistance.

Greases are also made in a range of different formulas. Many are calcium or lithium-based, the latter with a high melting point. Some greases are rubber-compatible, others contain molybdenum disulphide to provide dry lubrication. Greases with graphite improve both load-carrying and shock resistance.

Starting torque in a grease-lubricated ball bearing at low temperatures can be critical and may be excessive. At model engineering sizes, starting may become impossible when very cold. Under these circumstances, a low-temperature grease should be used. If the operating temperature range is wide, synthetic-fluid greases are a benefit. Greases are available to provide very low starting and running torques at temperatures well below freezing and may actually perform better than oil. It should be noted that starting torque depends on the unique properties of the chosen grease, experience may indicate the best choice.

The upper temperature limit for modern greases depends on the thermal and oxidation stability of the fluid and the effectiveness of the oxidation inhibitors. Petroleum-based greases are fine up to the maximum air temperatures found in the UK while synthetic oil-based ones can raise the useful operating temperature well above boiling point. This is particularly important for pre-lubricated bearings or in applications where re-greasing is simply not possible.

Water and moisture can quickly damage bearings. Using the right grease helps to protect from this type of problem. Calcium, lithium and non-soap greases are water-resistant but are poor at rust prevention. Sodium-soap greases emulsify with small amounts of moisture, preventing it from touching the bearing surfaces. This characteristic helps but emulsions are usually considered undesirable.

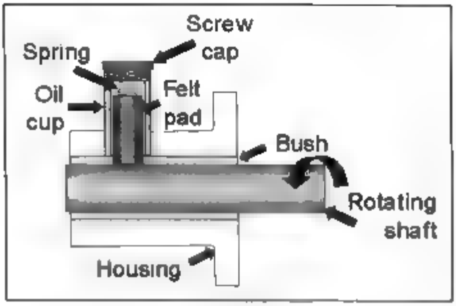

Figure 4. A plain-bearing felt-pad lubricator.

So, when searching for a grease for the bearings on a recently-completed model or a machine tool, the question is 'Which grease?' Perhaps the first port of call is to a supplier of materials to the automotive market. The list of products for this sector from just one manufacturer, Castrol, which is shown in Table 2, is quite daunting.

Multi-purpose greases can be used to lubricate the majority of model-engineers' bearing requirements. Special consider-ation may be needed where speed, load, temperature or environmental conditions are beyond the norm.

Low-viscosity greases reduce heat generation and required torque for high-speed or lightly loaded applications. High-viscosity greases suit moderate to low-speed applications and heavy loads.

Application of lubrication

Almost all model engineers employ an oil can to lubricate many of the bearings in their models but, mirroring full-size practice, automatic lubricators for plain bearings come in a wide range of different designs. Oil can be fed to bearings in many different ways, such

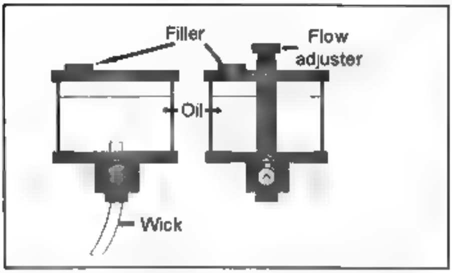

Figure 5. Left, a wick lubricator; right, a drip-feed lubricator.

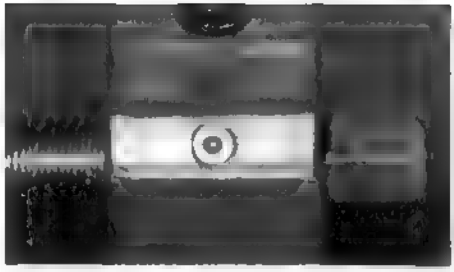

Figure 6. The oiling point fitted to the slide screw of a lathe.

as drip-feed, wick-feed or felt pad (Figure 4), pressurised circulating systems, oil-bath or air-oil mist. Each suits different types of model or full-size applications. Three more of these are illustrated in Figures 5 and 6.

Grease nipples may be fitted and the bearing housing filled from a grease gun but the minimum nipple size can be a difficulty. It is, however, not uncommon to find them fitted to full-size machine tools and bearing housings as in Figure 3 on Page 71, and they may also be fitted to some large-scale models.

Sealed bearings

Sealed bearings do not require any further lubrication. There are two reasons for choosing sealed bearings: to keep the dirt out and to retain the lubricant. Plain bearings can also be fitted with seals.

Chapter 2 has shown that there are numerous off-the-shelf ball and roller bearings that come with a range of different integrated seals. Pre-greased sealed bearings of this type can be considered as lubricated for life.

Self-lubricating bearings

There are several types of bearing that can be employed if complete freedom from the need for regular lubrication is an essential requirement. First, there are sintered bearings that employ a process of compressing powdered metal, usually bronze, to form a porous bearing that can then be impregnated with oil. Electric motors used to power machine tools often use this type of bearing and are 'lubricated for life'.

Other sintered bearings will require re-lubricating at regular intervals, typically once a year. A co-located felt washer with a suitable oiling hole may be used to wick oil into the sintered bearing while at the same time filtering out any dirt.

The other alternative is to use plastic plain, ball or roller bearings. Plastics like PTFE and nylon exhibit remarkably low coefficients of friction and, as a result of this factor and the relatively light loadings placed on them (they are unable to cope with heavy loads), heat generation is rarely a problem. And, of course, by their very nature, plastics do not corrode.

When using plastic ball bearings, there is no metal-to-metal contact, resulting again in low friction and minimal heat to dissipate. Thus they can operate satisfactorily without any oil or grease. Also, where plastic races are employed with stainless steel balls or rollers, corrosion is not a problem either.

Two-part roller bearings

Most roller-thrust bearings are supplied in two parts: the outer ring and the rest. The dot-

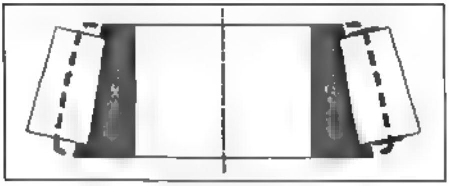

Figure 7. The areas to be grease-packed prior to installing a two-piece roller-thrust bearing.

ted areas in Figure 7 indicate where to pack the correct amount of grease into a two-part bearing prior to installation. It is important to work the grease into the bearing underneath the cage and around the rollers.

Re-packing stuffing boxes and glands

The time to re-pack a stuffing box is when the leakage rate (of steam, water or oil) becomes unacceptable, despite tightening the compression nut where fitted.

Cut four new rings of the right size from a length of impregnated yarn or PTFE thread by wrapping it around the exposed shaft (or a piece of metal of the same diameter) half a dozen times and then cut across the windings at an angle with a sharp knife.

Slacken the lock nut if fitted, undo the compression nut and slide this together with any compression spacer and lock nut along the shaft. If a bolt-on plate is fitted, this will require unbolting and likewise sliding along the shaft.

It is important to remove all of the existing packing as any left behind will reduce the chance of the new packing forming a tight seal, a task that usually requires a piece of bent wire and pliers. Insert the new packing, making sure the joint in each ring is offset from that of the previously inserted ring. Refit any compression spacer and the compression nut and screw the compression nut until hand-tight plus an additional quarter turn.

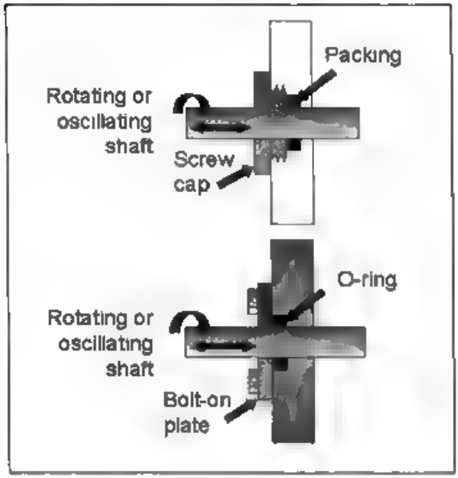

Figure 8. Two alternative types of stuffing box, one using packing, the other an O-ring. Either can employ a screw cap or a bolt-on plate to enclose the stuffing box.

Secure with the locking nut. Alternatively, replace the bolt-on plate.

Run the shaft for a couple of minutes and check for leakage and temperature. Adjust as needed, and then run for rather longer before checking that the box is not over-heating.

Replacement of an O-ring is a far simpler task and involves merely removing the old ring and replacing it with one of identical size

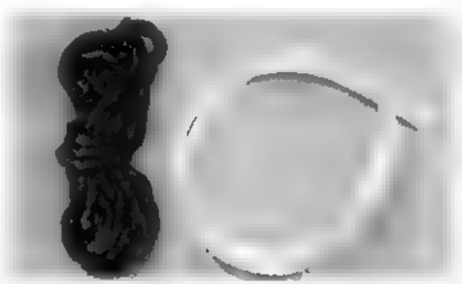

Figure 9. Left, graphite-impregnated yarn, right, PTFE thread. Both are good packing materials.

Figure 10. Steam power requires a lot of attention to providing adequate lubrication for all moving parts.

(both internal and external diameters) and material. Take care not to damage the O-ring itself during the fitting process, particularly by pinching the O-ring when tightening the screw cap if this is the method employed.

Steam engines

On steam engines, whether static or providing the motive power for any type of model, there is often a high demand for manual application of oil to individual bearings but, with some models, one or more oil reservoirs are provided.

The practice of building-in automatic continuous lubrication feed to machine bearings dates back to the start of the Industrial Revolution. The most widely used early solution was to install an oil cup mounted over each bearing, with a wick to provide a slow flow of the oil, using the capillary effect to drip the oil onto the bearing until all the oil had been used, when the cup would be refilled. Alternatively, an adjustable valve was fitted to the bottom of the cup to control the rate of flow of the oil. By the middle of the nineteenth century, improved lubrication systems were introduced, feeding oil from a reservoir via a network of pipes to all the bearing of a machine, with a regulator provided to control the rate of oil flow to each bearing.

The chosen oil must run easily from the chosen lubricator, should spread quickly and wet the bearing surfaces effectively. At normal feed rates it must stick to the bearing and not drip or be flung from the bearing. It must provide a strong oily film for both shock absorption and lubrication. The film needs to be hydrophobic to resist water or steam washing it from the bearing. It will assist in keeping dirt out of the bearing and wash out any that accumulates. Finally a film of oil will be provided that remains in place after shutdown to help prevent rust or other corrosion of the bearings.

Steam oil

Water displaces the majority of oils; this is the basis of operation of the displacement lubricator. However, animal-based oils and some specially compounded oils will lubricate in the presence of water and the latter are the basis of the oils used for model steam engines. The main additive is tallow (mutton, beef or other bovine fat that has been processed from suet) to help lubrication with wet steam.

Steam oil is available in several different forms and viscosities and with a variety of names. Some of the reasons for this include different steam pressures, temperatures and wetness, as well as various steam-pipe diam-

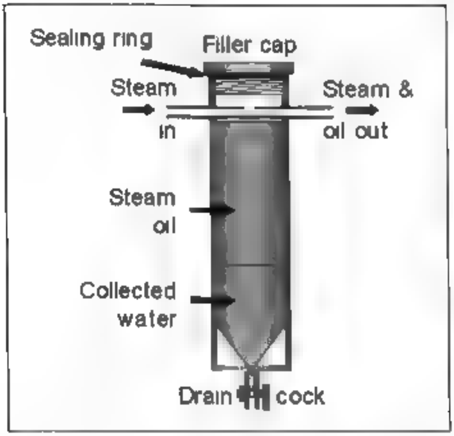

Figure 11. A displacement lubricator adds oil to the steam as some condenses to water and displaces the oil.

eters and lengths of pipe run, and the design and positioning of the lubricator in relation to the boiler, cylinders and super-heater if fitted.

Certainly there is no one steam oil that will suit all engines and where high temperatures at the cylinders are involved, a high-viscosity oil should be selected. It is important that none of the oil is reduced to carbon, blocking pipes and forming within the engine itself. A similar blocking can occur on engines with very small-diameter steam pipes when using high-viscosity oil.

In general, a medium-viscosity steam oil is a reasonable starting point. But if a super-heater is fitted to dry the steam, additives that are likely to cause carbon deposits in the pipes, particularly the super-heater itself, should be avoided.

The colour of steam oil indicates the type of base oil used as opposed to its viscosity.. It is also important to remember that any change in viscosity of the steam oil used is also likely to require a change in the amount

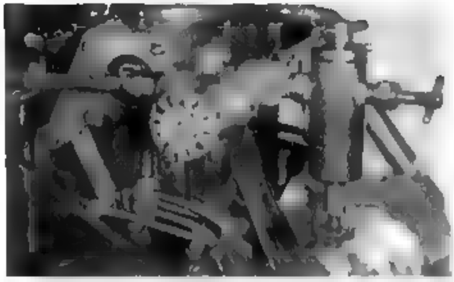

Figure 12. A displacement lubricator fitted to a Stuart Double Ten engine.

of oil feeding from the displacement or mechanical lubricator to the cylinders.

Displacement and mechanical lubricators

Displacement lubricators, an integral part of many steam engines, provide lubrication for the piston/ring/cylinder and valve/housing interfaces, the oil being carried into the valve housing and the cylinder by the incoming steam.

John Ramsbottom, a British engineer is usually considered to have invented the displacement lubricator in 1860. As shown in Figure 11, steam enters the displacement lubricator that lies between the boiler and the piston/cylinder/valve assembly. Due to the temperature difference between the steam leaving the boiler and the displacement lubricator, some of the steam condenses as drops of water. Due to their higher density, they sink below the lubricating oil, slowly displacing the oil upwards into the pipe leading to the valves and cylinders. Thus, while the engine is running, steam with a light mist of oil enters the valve chambers and cylinders. Many lubricators are fitted with some form of vernier adjustment for the rate of oil flow. Thus all that the operator is required to do is to empty the water from the lubricator and top up

Figure 13. A mechanical lubricator, top left, operated by the valve gear.

the oil level from time to time,. For obvious reasons, this should only be done when the steam output from the boiler is safely turned off and the lubricator has cooled down.

Many designs of displacement lubricator have and continue to be published in magazines like Model Engineer and a typical solution consists of a tube with a screw-top cap and a ring seal to allow the lubricator to be filled with oil. A steam pipe passes through the lubricator, with a small hole to enable steam to enter and oil to exit the lubricator. A means of draining water from the bottom of the lubricator is required and both the top cap and the drain must be able to withstand the maximum boiler pressure.

Only steam oil should be used in a displacement lubricator as it must be able to mix with steam and withstand the required temperatures.

Mechanical lubricators utilise a pump to feed oil to the steam cylinders and are an alternative to displacement lubricators. They provide the most positive way of metering the correct amount of lubricant to bearings. A typical unit consists of a small oscillating-cylinder pump installed inside an oil tank, driven by a ratchet and pawl arrangement. They inevitably tend to be more complex to build and less mechanically reliable in operation than displacement lubricators.

It is not the purpose of this chapter to show how to construct lubricators, merely to indicate how they may be used to provide lubrication on a wide range of steam models.

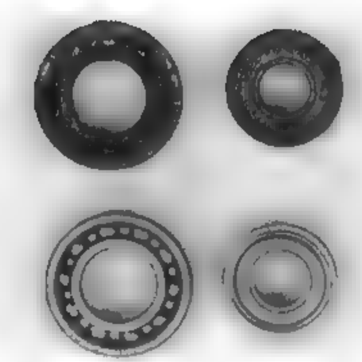

Figure 14. Examples (top) of bearings ruined by corrosion in a model four-stroke glow-plug engine and (bottom) new replacements.

Internal-combustion engines

Simple crankcase-scavenged two-stroke petrol- (as opposed to diesel-) powered motors use a fuel/oil mixture, usually around twenty parts fuel to one part of oil, to provide the necessary lubrication both for the bearings (main, big and little ends) as well as for the piston/ring interface with the cylinder. The fact that these engines have no mechanically operated valves certainly simplifies lubrication.

Some of the two-stroke oil passing through the engine is unburned and lubricates the internal moving parts. It also provides some cooling by transferring heat away from the hot cylinder head and piston out through the exhaust. The down side is the production of an oily exhaust residue.

Unfortunately, methanol will not mix with petroleum-based oil, so glow-plug engines use methanol mixed with castor oil, synthetic

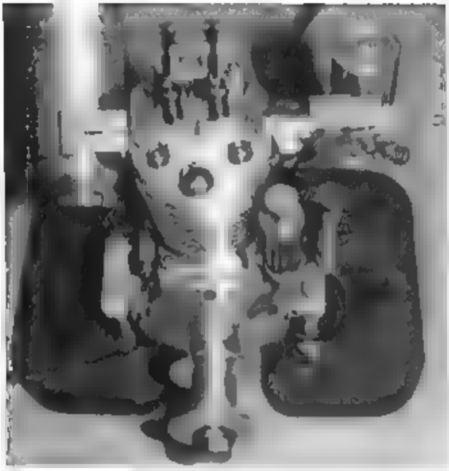

Figure 15. A complex lubrication system fitted to a single-cylinder four-stroke engine.

oil or a combination of the two. The recommended oil percentage varies from engine to engine but generally lies in the range from 15% to 20% oil by volume. Again, an oily exhaust is inevitable.

For use in sleeve-valve engines, pure castor-oil lubricants are not recommended because of their propensity to gumming and carbon deposition. Therefore preference must be given to using a synthetic lubricant-based fuel.

Most model four-strokes use the same system of a fuel/oil mix for lubrication, though some manual lubrication of the valve gear may be necessary. In addition, a suitable oil should be inserted into the crankcase at the end of each running session to avoid corrosion of the bearings caused by the acidic products of combustion, particularly nitromethane, that have leaked past the piston into the crankcase. Full-size and a few model four-stroke engines with extra complexity rely on splash or pumped oil in a wet sump or pumped oil from a dry-sump.

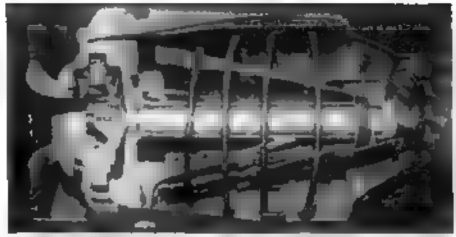

Figure 16. The bearings are clearly visible in this sectioned gas turbine.

Model diesel engines tend to use the inherent oily properties of their fuel to lubricate their moving parts and full-size diesel engines are noteworthy for their long working lives. Even their fuel injector pumps are self-lubricated by the fuel.

Gas turbines

Most model gas turbines also use a fuel/oil mix to lubricate their main bearings, but with only one moving part and two bearings, the major problem is dealing with the exceptionally high rotational speeds and temperatures. The normal practice is to mix 5% turbine oil, such as Aeroshell 500 or BP 2380, with the fuel and meter a small percentage of the resulting mixture through the bearings. Alternatively, a few designs use a separate 'total loss' oil system to feed directly to the bearings. In this case, a small oil tank is separately pressurised by an air bleed from the compressor to feeds the bearings. Oil consumption for a small home-built turbine is likely to be around 5ml (0.2oz) per minute and one certain way to destroy an engine is to forget to fill the oil tank before use. Regular maintenance is needed to check for either axial or radial play in the bearings, indicating the need for replacement. And it is worth noting that the bearing at the turbine end of the main shaft operates in a more adverse envi-

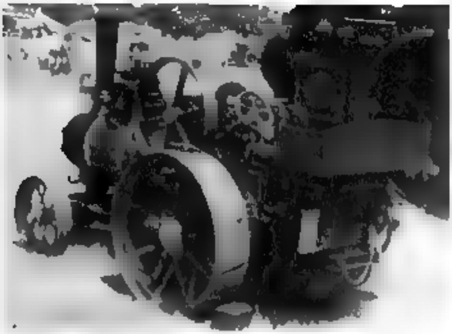

Figure 17. Conditions for scale traction engines and other vehicles at steam fairs very from dry and dusty to wet and muddy.

ronment due to the higher temperature levels found near the turbine.

Gearboxes

Many models are fitted with gearboxes. Typical examples include steam lorries, traction engines and internal-combustion-engine-powered vehicles. The major requirements are for the gearboxes to be oil tight and for the bearings and gears to all be well lubricated. Normally an automobile multi-grade oil is fine for such applications. Turboprop, locomotive and helicopter gas turbines will require fairly complex designs of reduction gear that involve lubrication problems all of their own. However, in comparison with the difficulties associated with the high-speed bearings on the main shaft, the problems are relatively conventional.

Road and cross-country vehicles

While model locomotives operate on relatively clean rails, model traction engines, trucks, cars and tracked vehicles operate in a generally more dusty or muddy environment where the dirt needs to be kept out of the bearings. This predicates selecting sealed ball or roller bearings that should provide problem-free operation. Where the look of the prototype precludes the selection of such bearings, great care must be taken to keep the bearings sealed, say with felt washers, and clean as well as ensuring that adequate lubrication is available to the bearings.

Figure 18. This hot-air engine's bearings are low friction and require minimal lubrication.

Hot-air engines

The main problem to be considered when lubricating hot-air engines is the need to minimise friction, as the power output of these engines is relatively low. Thus, oil rather than grease is always better and the choice of a small amount of low-viscosity oil is recommended. Often, the preferred solution is to use bearings that do not need any lubrication, such as steel running in PTFE or nylon. The other main consideration is to protect the bearings (and their lubricants) from the effects of heat emanating from the hot end of the engine.

Figure 19. The prop shaft and rudder bearings of any boat are likely to be exposed to water that may be salty.

Boats

The difference between boats and other models is their operating environment. Most lakes and other areas suitable for boating also prohibit the release of oil into the water in order to prevent damage to any plant and animal life. This has some impact for both lubrication of the prop shaft and other under-water bearings as well as the release of oil-contaminated water when exhaust steam condenses. In addition, water provides the perfect environment for rusting, something to be avoided in any bearing, and the issue is even more serious when operating in salt water. Thus there is a preference for plastic (PTFE or nylon) bearings both for the lower end of the prop shaft and for the rudder (and submarines' hydroplane).

Wooden models

The bearings of carriages, carts and other models made entirely or largely from wood usually do not require a great deal of special attention to the lubrication. They are mostly static models and their bearings are rarely used. Thus, whether metal or wooden, the occasional application of a small amount of grease will generally suffice.

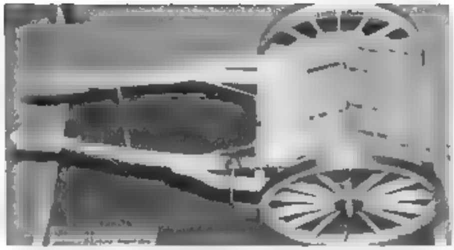

Figure 20. The bearings of this LNER tumbler cart are unlikely to see much use.

Clock and watch bearings

The majority of clock and watch bearings are either pivot or plain bearings, where a steel shaft runs in a brass bearing. Lubrication of these bearings needs to be done with care. When a clock is running (normally 24/7) lubrication will not prevent wear but only slow it down. Any tendency of the oil to dry out will increase the friction and with so little available drive power, the clock will stop.

A key factor in reducing wear is to use the correct type of lubricant and, as with steam oil, there are many different clock and watch oils available. Only good-quality clock oil, produced to inhibit thickening, should be used on movements. Other oils will congeal and dry up, causing the movement to wear and then cease to function. A issue when oiling is to avoid applying too much and the use of a small syringe will help to place a small drop exactly where it is needed. A clock pivot requires only enough oil to fill the space between it and its hole. The oil cups should be filled not quite to the top. If a cup is overfilled and oil runs down the clock plate, over time the cup will be drained of oil and this will cause problems.

It is important not to lubricate a clock or watch before it has been properly cleaned.

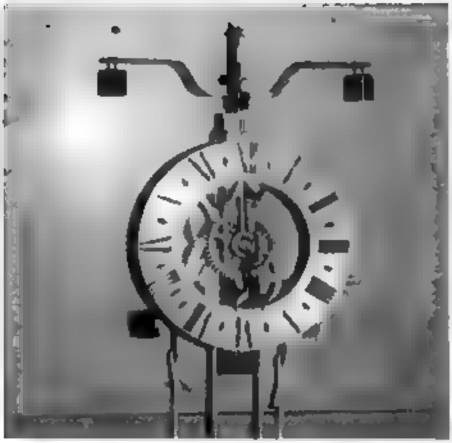

Figure 21. The construction and lubrication of clock bearings are specialist tasks.

Otherwise the remains of the old lubricant are likely to contaminate the new one and degrade its effectiveness. It is also worth remembering that older clock lubricants were organic and were usually manufactured from whale by-products, resulting in an unstable oil that degraded with time and also had a corrosive effect.

Clock and watch oil

Clock and watch oils are manufactured to specialist specifications suited to this particular application. When lubricating a watch or clock, choose a heavier oil for high-torque, low-speed applications (mainspring, 1st and 2nd wheel pivots) but a lighter one for low-torque, high-speed applications (3rd and 4th wheel pivots as well as the escape-wheel pivots). For clocks that will run in a centrally heated house, thinner lubricants designed for use in cold conditions should be avoided.

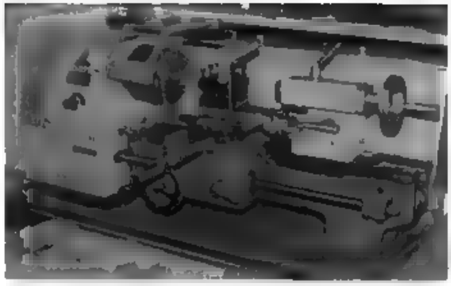

Figure 22. The moving parts of any lathe require regular lubrication.

Machine tools

Many model engineers take pride in maintaining and sometimes totally or partially refurbishing their own machine tools.

While such tools are built with two types of bearing, rotational ones for the chuck and linear ones for the slides, it is the latter that tend to need the most attention from a lubrication and adjustment point of view.

Myfords recommend Castrol moly grease for lubricating change wheels, feed screws and lead screws, H32 Nuto oil for the headstock spindle, tail-stock barrel and Oilite bushes, and Febis K68 oil for bed, slide ways and gearbox. It would be hard to find a better recommendation.

Slides need their gib strips checked and reset from time to time and on occasions it will be necessary to remove a slide for cleaning. While the slide is removed, apply a light coating of white-lithium grease to the gib face, the dovetail faces and the lead screw. This grease is widely available from model-engineering suppliers and DIY stores in small plastic tubes which will last quite a while.

CHAPTER 6

Which type of bearing to use

Introduction

Model engineers often ask which sort of bearing is the best, and the answer is that it depends on the application. The choice of bearing is also heavily influenced by the environment in which the model will operate. There is the world of difference between, as an example, an exhibition-quality static steam engine that will spend the vast majority of its life under a glass cover, rather than under steam, and a working quarter-scale traction engine.

So what are the many and varied factors that should be taken into consideration? The list given in Table 1 includes many of the issues that are important. For any particular model, some parameters will be more relevant than others, so that it is essential to think carefully about each item on the list and how it will or will not apply to the chosen model. Of course, if the model is to be built from a set of plans, then the designer will have considered the bearings and specified suitable solutions. Occasionally, particularly in designs from the first half of the twentieth century, enhanced bearing solutions are available today and some bearing alterations may prove beneficial.

Easy to make

Probably the most straightforward bearings to make comprise a pair of holes drilled to

Easy or hard to make	Fit and tolerances needed
Cost	Precision required
Availability	Corrosion resistance
Friction level	Dust and dirt resistance
Size needed	Lubrication requirements
Load capability	Liquid or gas retention
Safe operating-speed range	Similarity to bearings in prototype
Operational temperature range	Expected operating life
Method of bearing retention	Ease of installation/maintenance

Table 1. A list of important considerations when choosing which bearing to use for a particular application.

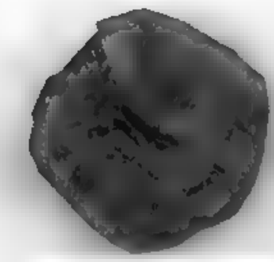

Figure 1. Quality ball and roller bearings will be supplied wrapped in rust-preventing paper.

hold a steel shaft that gets little movement and never actually rotates through 360°. The bearings will be slightly harder to make if continuous rotation is needed and this may mean that the holes have to be reamed. The work involved becomes even harder if they need to be honed or polished.

Making a housing for a purchased bearing involves drilling or boring a suitable size hole, keeping in mind the tolerances on the fit, and devising a retention method.

Linear bearings usually require a lot more work to make and the preparation of suitably flat or circular mating surfaces demands a fair degree of skill and practice. It may involve an expertise in scraping, honing, lapping and polishing.

Clearly, it is beyond the skill of the amateur to make ball or roller bearings except, perhaps, those used for supporting the weight of some rotating items, such as roundabouts. Thus there will often be a need to purchase ready-made rolling bearing for many requirements, particularly for models of more modern prototypes and for full-size applications.

Cost and availability

There is a wide range of off-the-shelf plain bearings and bushes on the market, as well as ball, roller and needle bearings. Whether the desired size or sizes can be found is quite another issue; bearing suppliers tend to hold large quantities in stock, but not necessarily in the relatively small sizes applicable to model engineering. Thus, it should always be borne in mind that the process of finding and purchasing the right bearing for the job may prove to be quite a time-consuming task.

A number of suppliers who attend model-engineering exhibitions offer a limited selection of what appear to be 'end of stock' bearings. It is essential to check their condition before purchase. Some older published plans may specify bearings in sizes that are no longer available and this may become more of a problem as the world inexorably moves towards metrication. It is also a particular problem for anyone involved in restoration work where the original bearings are almost invariably in imperial sizes.

Ready-made bearings will inevitably add to the cost of making or refurbishing a model or full-size item, and some off-the-shelf items can be expensive. Larger ball and roller bearings tend to be more expensive than smaller ones, though there may well be a premium on sub-miniature sizes. Better quality and performance also increase cost.

As an example, the following prices applied to replacement headstock bearings for a Myford Super 7 lathe in 2007: spindle bearing – front £27.35; angular-contact bearings £19.89 each.

Friction

Many models require very low levels of friction, both to operate satisfactorily and to minimise the torque required at start up. Hot-air engines and clocks spring to mind in this category but some models are much more

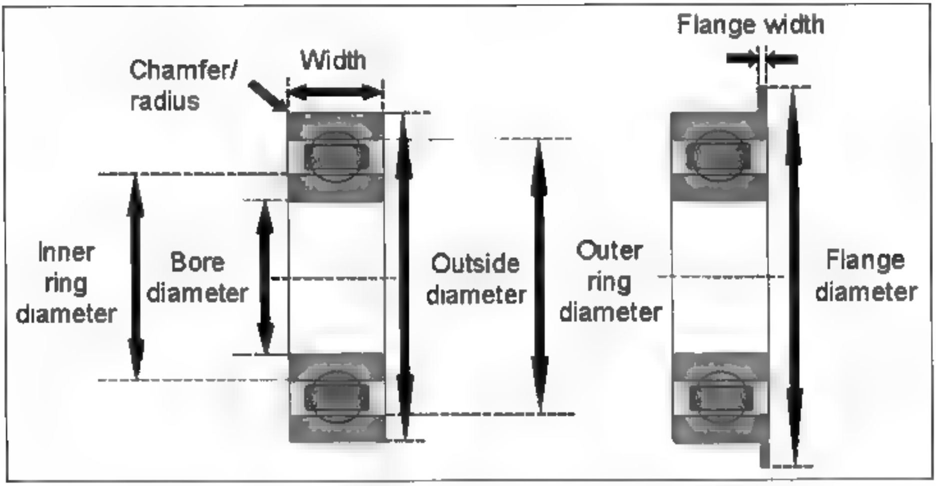

Figure 2. It is essential to have worked out the main dimensions of a bearing before making a new purchase.

sensitive to bearing friction than others.

Plain bearings, even the coned bearings widely used on clocks, offer higher levels of friction than ball bearings, which themselves involve more friction than roller bearings. Plain bearings made from plastics, such as PTFE, provide lower friction levels than those made from metal and also do not need to be lubricated. Friction can also further be decreased by minimising the surface area of the bearing at the cost, however, of load-bearing capability and likely working life.

Perhaps fortunately, it is rare for model engineers to be interested in the operating efficiency of their model, entrants to IMLEC and similar efficiency competitions excepted, so that the work involved in overcoming frictional losses is rarely an issue in steam- and internal-combustion-powered models.

Size

Most model requirements for bearings are driven by the need for small or even miniature bearings. The sizes of ready-made bearings used by modellers tend to be at the bottom end of the available size range. Even where bigger bearings are needed for large-scale or full-size applications, they are nowhere near the size of the large bearings needed, for example, in the engines of super-tankers or in power-station generators. It should be noted that, for a given internal diameter, needle bearings have a smaller external diameter than equivalent ball or roller bearings and also tend to weigh less.

When purchasing ball bearings, the standard bottom-end size is generally 3mm internal diameter, 10mm external diameter and 4mm wide. Roller bearings are larger and it is not uncommon to find internal-bore sizes starting at 12.7mm. Needle bearings are available

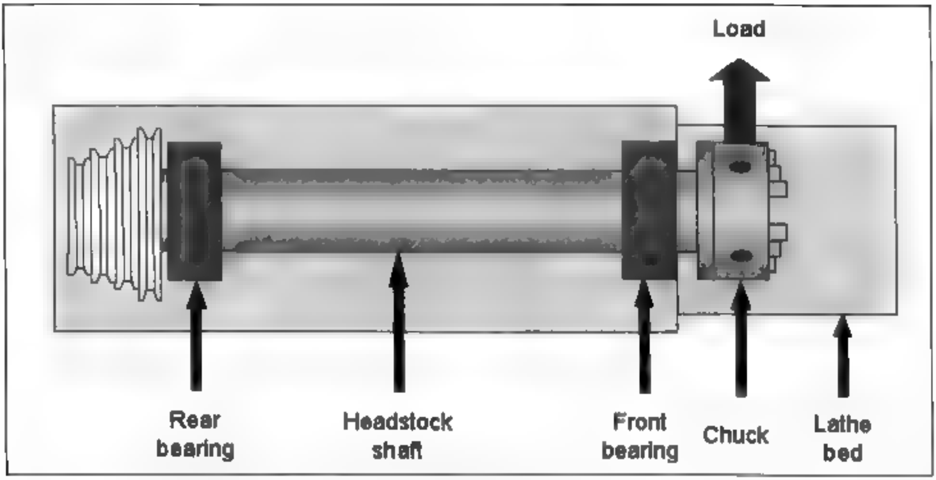

Figure 3. In this plan view of a lathe the side load will be caused by the cutting tool. It is therefore important that the front bearing is as close as possible to the load.

with 3mm internal diameter but with a comparatively small external diameter of 7mm and a 6mm width. The upper size limits are unimportant to model engineers, even when working with full-size machine tools, since bearings with diameters of over 2m are not uncommon. There are similar size ranges for imperial bearings.

For the smallest possible sizes, instrument ball bearings are readily available in sizes down to well under 1mm bore diameter but at a price that reflects their precision construction.

Load capacity

Models rarely have to sustain really heavy loads, though some large-scale traction engines and locomotives apply significant loadings to many of their bearings, mainly the weight of the driver and passengers. In addition, Chapter 8 looks at a few full-size applications, such as machine tools, where some loadings can be high. Of course, model engineers are renowned for enjoying working on 1:1 models, such as cars and motor cycles, where loads are inevitably much higher than in the model field.

Large-area plain bearings help to spread any load, while roller bearings, with a large contact area between their rollers and races, will support a greater burden than the equivalent size of ball bearing. The load distribution in relation to the bearings also needs some thought as the illustration of a lathe headstock in Figure 3 shows. The further from the front bearing the load on the chuck is placed, the greater the leverage it applies to the front bearing.

Equally, many modellers have experienced a shaft that is being turned between centres (bearings) flexing when the cutting tool approaches the mid-point. The use of a moving steady can help to overcome this problem. Thus an additional bearing or bearings on a long shaft can significantly reduce the chances of the shaft bending under load.

Speed capability

Some requirements, such as the bearings on brake linkages, never fully rotate through 360° and see relatively little use.

Model reciprocating steam engines rarely exceed 1,000 rpm, while only a few model reciprocating internal-combustion engines exceed 10,000 rpm. Model gas turbines regularly run at 100,000 rpm and some can reach twice that speed.

Plain bearings become increasingly unsuitable as rotational speeds rise above a few thousand rpm. For ball or roller bearings, it is the centrifugal forces that limit the maximum speed of the bearing and, of course, the higher the speed, the greater the potential for wear to the races and balls/rollers. The smaller the diameter of the bearing, the greater the maximum speed it can tolerate, all other things being equal.

The application of modern technology has meant that small ceramic bearings will tolerate operating speeds of several hundred thousand rpm and still provide a reasonable life expectancy. These bearings, when provided with adequate lubrication, will work well at the rotational speeds found in model gas turbines – the area of model engineering most likely to need the highest rotational speeds.

Temperature effects

Closely related to the speed factor is the operating temperature of a bearing. Plastic bearings are particularly limited in the maximum temperature they can tolerate. A primary task of lubrication is to remove excess heat, but some bearings are forced, by the very nature of the model in which they are fitted, to operate at elevated temperatures. Good examples

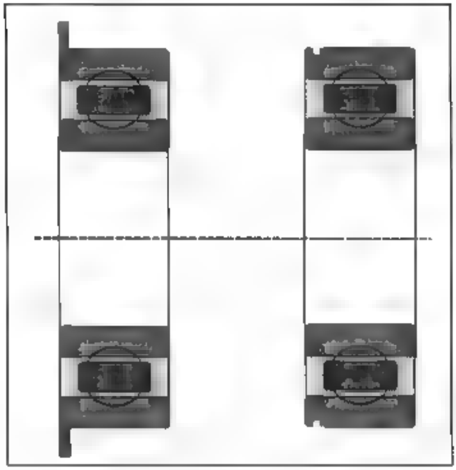

Figure 4. A pair of ball races: left, with a flange; right, with a snap-ring groove.

of this are internal-combustion engines, both reciprocating and rotary variants. However, for most applications, bearing temperatures are unlikely to exceed 100°C and the most important way of avoiding excessive temperatures is to ensure a good flow of lubrication to carry away the heat. Internal combustion-engine valves also require the valve stems and guides to be good heat conductors to increase heat transfer away from the valve heads.

Bearing retention

Off-the-shelf bushes and rolling bearings can be supplied with flanges, or grooves on their outside for circlip retention. Alternatively an anaerobic retention adhesive may be employed. Sometimes a split-bearing holder is the solution and this is frequently found on model steam engines, as well as in the main and big-end bearings of internal-combustion engines.

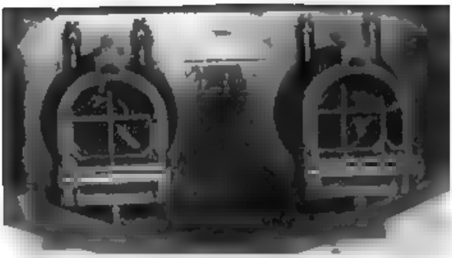

Figure 5. This complex propulsion unit requires many corrosion-resistant bearings.

When building to an existing design, the preferred method of bearing retention will normally be indicated on the drawing. However, when building from scratch, thought is needed to ensure that a positive and, if required, scale-like retention method is employed to hold the bearings in position.

Fit and tolerances

Two important issues are how little play, or slop, is acceptable in a bearing and what tolerances are necessary between the diameter of the bearing and the size of the housing in which it is to be fitted. In machine tools, a lack of any excess play in the bearings is of great importance and, in slides, the gib strips are provided to take up any wear. In other cases, such as model gas turbines, the gap between the turbine and its casing is minimal to ensure maximum efficiency. Any play in the bearings is likely to cause the turbine to touch the casing and destroy itself. Thus preloading bearings, described in Chapter 2, can ensure that any play in the bearings is set to an absolute minimum. On the other hand, a small degree of slop in a linkage, say to locomotive brakes, can be acceptable.

Precision

It is possible to purchase super-precision rolling bearings and, with a suitable lathe headstock and pre-load, work can be held to a roundness of some 9 thousandths of a millimetre (35 millionths of an inch)! Such accuracy can safely be said to never be required by model engineers. Standard rolling bearings, with suitable pre-load, will suffice even for the most demanding of modellers' applications.

Corrosion resistance

The models built by engineers fall into two categories: those that are for display only, or are run in a benign environment, and those that operate in corrosive conditions. In the latter category are models exposed to water and, in particular to salt water; model boats, their power trains and other moving parts. However, any steam engine will involve water and the potential for rust in any steel or iron bearings. A particular problem that has been experienced by builders of model four-stroke engines is corrosion of the main bearings caused by the acidic residue of the combustion of nitro-methane-based fuel leaking into the crankcase. While the use of oil and grease can help to protect the bearings against the worst ravages of corrosion, it is best to try and use corrosion-resistant bearings wherever possible. Plastic and ceramic bearings offer the best protection in this respect, while some of the brasses and bronzes offer good corrosion resistance as well. The use of post-operation water-displacing oil will also help.

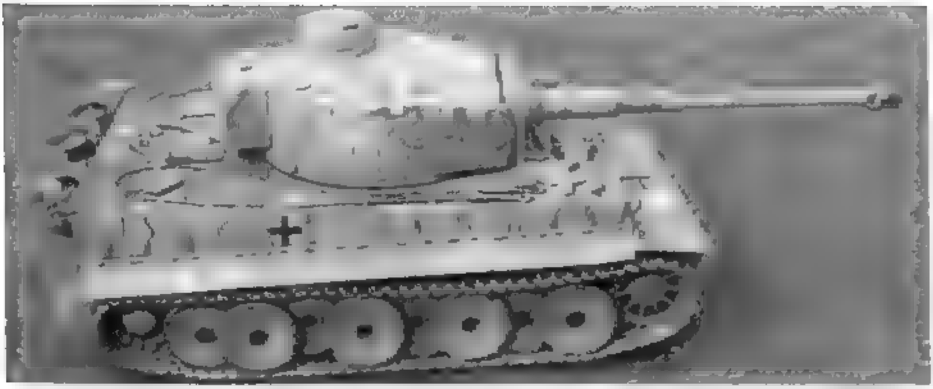

Figure 6. Tank wheel bearings and track links are likely to experience dusty conditions.

Dirt and dust resistance

One factor affecting the choice of open or sealed bearings is the amount of dirt and dust to which a bearing may be exposed. Any land vehicle is likely to operate in dusty or even muddy conditions and the bearings will need to be protected from dirt. At the other extreme, many clock-builders keep their timepieces under glass domes to protect the working parts from the dust found in any home.

Ball and roller bearings can be purchased with built-in seals to protect them from the ingress of dust and dirt while home-made plain bearings can be protected by oil-impregnated felt pads.

However, it should always be remembered that any bearings themselves will shed minute particles of metal as they are used that will itself also increase their wear rate.

Lubrication

The type and quantity of lubricant that any bearing needs is an important factor to consider. In some cases, a bearing that is lubrication-free may be what is wanted. Many ball and roller bearings are lubricated for life and sintered bearings rarely need attention. On the other hand, it may seem to be essential or prototypical to provide some sort of overt lubrication and this may require an independent oiling system to be built into the model as, for example, in some internal-combustion engines. Steam engines are usually fitted with a mechanical or displacement lubricator for the cylinders and valve gear. Chapter 5 deals with a number of lubrication alternatives.

Liquid and gas retention

Bearings fitted to crankcases and gearboxes may be required to perform a secondary task of retaining the oil placed in them. Likewise, the glands on steam cylinders and valve gear need to be steam-resistant while model-boat propeller shafts, rudders and, in the case of submarines, hydroplanes will also need waterproof glands.

Careful though needs to be given, not only to the category of bearing if there is a choice, but also to the individual configuration of the

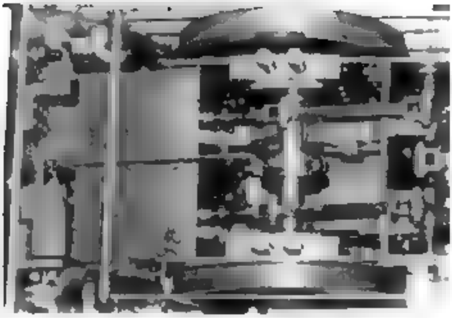

Figure 7. There are places, like the glands on piston and valve-operating rods, where bearings must be steam-proof.

bearing. A gland or a stuffing box is probably one of the best ways of achieving the degree of sealing required and these are discussed in detail in Chapter 3. Alternatively, where the need is to minimise the oil outflow from a bearing, a felt washer may suffice. Ball and roller bearings can usually be supplied complete with in-built seals, making them completely liquid proof.

Matching bearings in prototype

Clocks that are reproductions of well-loved historical designs would certainly not look right with ball bearings fitted in the clock plates, even if such a solution were practical. Likewise, ball-raced main bearings on a model of a mill engine would look equally out of place.

It is important to match the type of bearing used in the prototype when making any scale model and this is fairly easy when building from a published plan or kit, where the bearings are specified. Equally it is not hard to make plain bearings for new designs, especially where castings exist for awkward shapes.

Figure 8. This is not the sort of prototype where ball bearings would be appropriate.

Expected operating life

Purchased bearings are designed for a particular life and the various types of bearings made in the model-engineer's workshop will also have an expected life. Except in the case of full-size items like clocks and machine tools, and highly stressed bearings such as those in gas turbines, the life expectancy of bearings is not often a major consideration for model engineers. However, it is important to remember that many factors affect the life of any bearing, of which lubrication, dealt with in the previous chapter, is a crucial issue for all except bearings that are self-lubricating.

Other factors that can impact on the expected life of a bearing include temperature, corrosion, speed and loading. It is also important to understand that irregular use of a model can result in congealing or drying out of the lubricant in the bearing. A particular example

of this is found in model internal-combustion engines which use castor oil in their fuel. Left over a period of a few months, the castor oil will congeal to the extent that the engine cannot easily be turned over and sometimes appears to have completely seized.

Ease of installation, repair or replacement

Before construction starts some thought should be given to the subject of how the bearings are going to be installed. A few models, particularly those that get a lot of use, will eventually wear out their bearings and require them to be replaced. High-revving engines, particularly gas turbines, are an example of this. Also some steam locomotives will require a major overhaul after running maybe a few thousand miles, with significant work being required on all bearing surfaces, both linear and rotary. Clocks, of course, run continuously, resulting in gradual wear to their bearings, and rework, rather than replacement, is the norm.

Re-fitting ball and roller bearings is a straightforward task, although it may require the model to be partly disassembled to gain access to the bearings. These are issues that require thought during the design phase of any model. Replacement of machine-tool bearings is often more concerned with maintaining accuracy and repeatability. Thus re-fitting the headstock bearings of a lathe can be a daunting task. Another issue is whether the original size of bearing is still manufactured and can be obtained.

Clocks are a special case as their bearings do wear, the holes in the clock plates becoming oval due to wear rather than their original round shape. They then require considerable work to restore them to pristine condition.

Gib strips on machine-tool beds and cross-slides have built-in adjustments to take up wear. The process of adjusting gib strips is described in Chapter 4. However, when the slides or bed are too worn for the wear to be taken up, an expensive re-grind of the bed becomes necessary.

What to purchase

As far as most ball and roller bearings are concerned, it is possible to purchase economy bearings that will suit the price-conscious model engineer. At some exhibitions, it is possible to pick up very low-cost bearings, often end of stock from manufacturers or companies that integrate bearings into their products.

High-speed bearings that can cope with elevated heat levels are usually fitted with seals to help reduce corrosion. Stainless-steel bearings take anti-corrosion a stage further and can deal with significant amounts of moisture. Improved performance with high-quality seals can also minimise the impact of operating in a corrosive environment. Finally, there are hybrid- and full-ceramic bearings that can deal with the highest speeds and temperatures, but at a price. Details of these types of bearings are given in Chapter 4.

The normal bearing parameters of most interest to the model engineer are: the bore diameter (Will it fit on my shaft?); outside diameter and width (Will it fit in my housing?); how will it be retained (Does it have a flange or circlip groove?); whether it has a shield or seal (Will it operate in the actual environment where I will run it?); and what are its load and speed limitations (Is it up to the job in hand?). Figure 2 on page 87 indicates how the measurements are taken that appear on bearing-suppliers' brochures and web sites.

Bearing type		Advantages
Plain	Aluminium	Light weight
	Babbitt/white metal	Hard-wearing
	Brass	Corrosion-resistant, good with steel
	Bronze & phosphor bronze	Corrosion-resistant, good with steel
	Gunmetal	Corrosion-resistant, good with steel
	Pivot	Good for clocks and watches
	Steel	Good for shafts and frames
	Sintered	Virtually lubrication-free
	Plastic	Lubrication free, corrosion-resistant
	Thrust collars	Good for axial loading
Ball	Plain	Low friction, good with radial forces
	Self-aligning	Ideal where shaft alignment suspect
	Thrust	Good where axial forces present
	Re-circulating balls	High precision
	Ceramic	Capable of highest speeds, high temperatures, long life and corrosion resistance
Roller	Plain	Good for high radial loads
	Taper	Can carry axial as well as radial loads
	Linear	Take heavy oscillating loads
	Self-aligning	Ideal where shaft alignment suspect
	Needle	Small outside diameter; low space occupancy
Linear	Brass	Good with steel
	Bronze & phosphor bronze	Good with steel
	Cast iron	Built-in graphite makes it wear-resistant & able to operate with poor lubrication
	Gunmetal	Can be used as a bearing in conjunction with itself
	Steel	Good with steel
		Ideal for shafts
Glands		
	Graphited yarn	Traditional
	PTFE thread	Easier to fit than graphited yarn
	O-rings	

Table 2. A table showing the advantages, disadvantages and suitable applications for a range

Bearing suppliers

Purchasing bearings should not pose great difficulties, though the particular bearing wanted may not be so easy to find. There are several sources of ready-made bearings: high-street bearing shops (details in Yellow Pages) and Internet bearing suppliers, model-

Disadvantages
High wear rate
Hard to make and fit
Awkward to drill
Wear unevenly.; hard to repair
Prone to rust unless stainless
Difficult to alter internal diameter
Low load capacity
Increased friction
Poor for axial forces
Poor for axial forces
Poor for radial loads
Expensive, reverse driveable
Relatively expensive
Poor for high axial forces
Expense
Expense
Reduced load capacity
Awkward to drill
Weight, prone to rust
Rusts, poor running in steel bearing
Awkward to fit
None
Getting the right size may be hard

of plain, rolling and linear bearings.

engineering stockists, the suppliers of original equipment when replacement bearings are needed, and some companies at model-engineering exhibitions that often also offer

Figure 9. A display on a stand at the 2007 Model Engineering Exhibition offering a wide selection of bearings.

end-of-run, excess stock disposal or 'second-hand' but unused bearings in a range of different sizes.

Lazy Susan bearings are obtained from companies that deal with the construction of wooden items, though one well-known machine-tool supplier also offers such bearings.

Conclusions

Table 2 lists the various types of bearing discussed in the first four chapters and considers their advantages and disadvantages, to help decide which might be the best suited to individual applications.

Plain bearings must inevitably be the first port of call for anyone starting either to design or to build a model. While they require a level of skill to make, the simpler ones, used for example in linkages, provide an ideal learning process. Furthermore, they can be customised to the particular application and there is a degree of satisfaction inherent in their successful completion.

The use of ball, roller or needle bearings presents few problems apart from the ability to measure accurately, to find a supplier

of the required bearing and the skill to bore out the correct size of housing. Consideration must also be given to some suitable form of retention.

Linear bearings are commonplace on every type of reciprocating engine and are also found in steam-engine crossheads. In full-size equipment, they are an integral part of virtually every type of machine tool.

Clock-makers tend to be skilled in the production of pivot bearings. However, this type of bearing is seldom employed outside this particular branch of the hobby.

CHAPTER 7

Modelling applications

Introduction

This chapter looks at many of the wide range of different types of projects that model engineers may undertake, considers the various categories of bearings required and looks at the preferred solutions for each particular application. It is fortunate that the scale effect means that the bearings in models are generally less heavily loaded than their full-size prototypes. There are a few exceptions, such as the increased loading that results when a model has to carry the additional weight of a human being. Furthermore, while the scale effect helps with loading, it has the opposite impact on rotational speed, which can be a serious concern with high-revving internal-combustion engines, particularly jet engines.

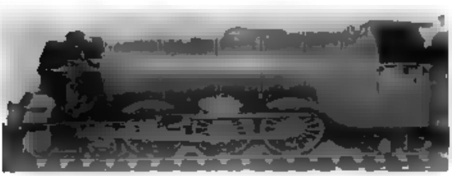

Figure 1. A Pacific locomotive needs plenty of work to ensure that all rotary- and linear-moving parts operate without excessive wear.

Steam-powered models

There must be thousands of different designs of steam-powered models, the majority of prototypes being conceived before the widespread availability of mass-produced ball and roller bearings. For the purposes of this chapter, it is useful to categorise these models into a number of groups. So first, railway locomotives and their carriages and wagons are covered.

Locomotives and rolling stock

The average steam locomotive requires, as a minimum, both plain rotating and sliding bearings, and some builders may occasionally choose to use ball and/or roller bearings. The first need is to get a rolling chassis and this requires the selection of suitable materials for the axles and axle boxes, as well as the horn blocks: usually silver steel, sometimes just mild steel, for the axles, and one of the bronzes or brass for the bearings. For locomotives, the pistons, cylinders and valve gear will require similar choices to be made, with cast iron or bronze being popular choices and ideal for interfacing with steel parts. Many of the linkages, such as those for the regulator,

Figure 2. Building rolling stock requires skill in both metal- and wood-working.

reversing gear and whistle, will also need thought in making up the necessary pivots that require little and slow movement. Usually steel running in steel is adequate for such restricted movements. In all cases, decisions are needed on how lubrication is to be carried out: automatically or manually, with a mechanical lubricator usual for getting oil to the cylinders and valve gear.

Traction engines

The building of a scale or semi-scale steam-powered traction engine is a long-term project that will require careful construction of the various bearings needed and provision to be made for their lubrication. Some parts, like the wheels and flywheel, may involve relatively heavy loadings and long operating lives, depending on their size and usage. Others, like the steering pivot, involve rotation over only a limited angle, but have to bear a substantial proportion of the weight of the engine. Plain bearings, as used in the prototypes, are the normal choice, again with steel parts running in cast iron or one of the bronzes.

The piston, cylinder and valve gear are relatively accessible (except perhaps on showman's engines), providing good opportunities for the fitting of lubrication reservoirs or manual lubrication. All linkages and their pivots also tend to be reasonably accessible for the odd drop of oil or grease. An additional factor that is also a concern for any steam-powered vehicle is the dusty and sometimes muddy environment in which these vehicles often operate. This requires regular cleaning, sealed bearings where possible and a good system of lubrication.

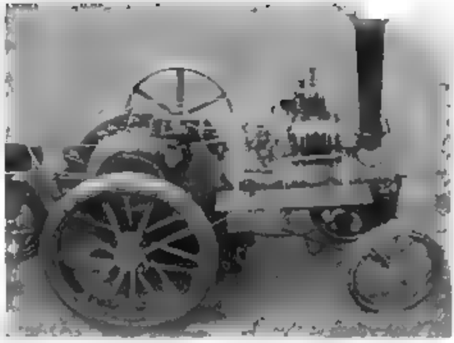

Figure 3. Traction engine wheel and steering bearings require careful attention.

Other steam-powered road vehicles

From a bearing point of view, there is little difference between the needs of model steam lorries, steam cars or even steam motor bikes. While plain bearings are quite adequate and often prototypical for the road wheels, scale models may, on occasions, employ ball bearings in their place. The engines have similar

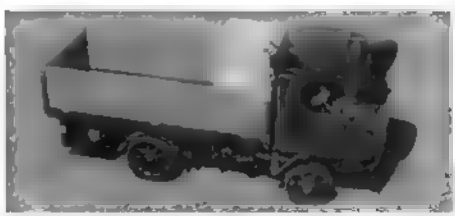

Figure 4. Small steam lorries usually lack excess power and need low-friction bearings.

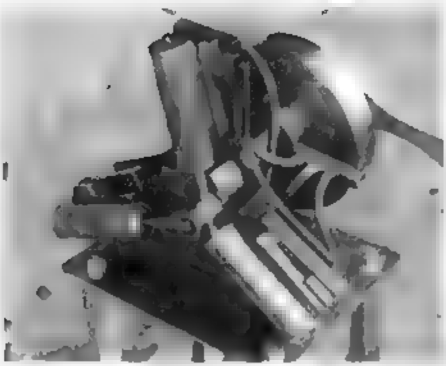

Figure 5. A three-cylinder steam engine with a propeller mounted in front of the flywheel.

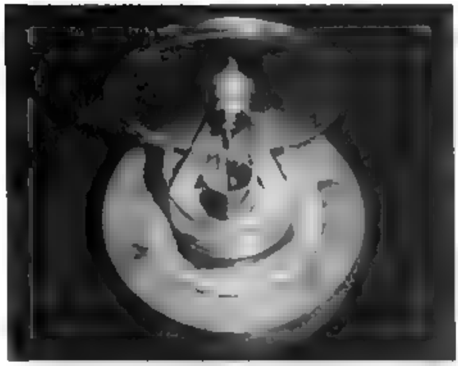

Figure 6. All hot-air engines require low-friction bearings to minimise power losses.

bearing needs to steam locomotives and traction engines but almost inevitably access for lubrication tends to be difficult.

Static steam engines

There is a huge variation in the types of static steam engine that can be built and it is not uncommon to find exhibition-quality marine engines displayed as static models. Often static engines are run on compressed air rather than steam, in which case displacement lubricators will not provide adequate lubrication to the cylinders or valve gear so that care must be taken to ensure sufficient lubrication by other means. Otherwise, the bearing requirements of these models are similar to those of steam-powered vehicles.

Hot-air engines

Hot-air engines place very high demands on the choice of bearing because the power output of these engines tends to be low and it is essential to minimise the friction losses in any bearings. Thus low-friction pairs of materials are regularly chosen for areas like pistons and cylinders and, if the model is sufficiently large, ball races may be favoured for rotating parts. PTFE and nylon are popular bearing materials and, in the case of cylinders, care must be taken to ensure that the coefficients of expansion of the piston and cylinder materials are similar. Displacer cylinders are sometimes created from glass, Perspex or acrylic, with pistons made from expanded polystyrene.

Internal-combustion engines

Petrol, diesel and glow-plug engines all provide a relatively high power-to-weight ratio compared to steam engines. And they require careful thought about the various bearings they need. A simple two-stroke, single-cylinder petrol or glow-plug engine will need big-end, little-end and main bearings as well as the selection of a suitable combination of materials for the cylinder and piston, the crankshaft and gudgeon pin. The main bearings may be plain ones or a pair of ball bearings can be used. Aluminium alloy is a popular choice for connecting rods and

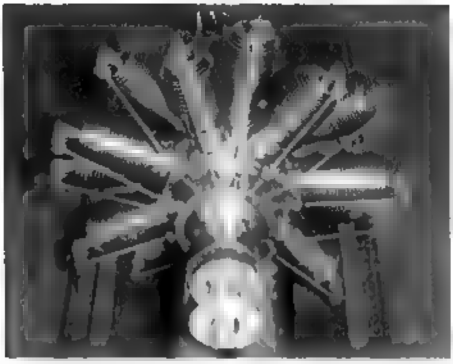

Figure 7. The big-end bearings of a radial engine require great care during construction.

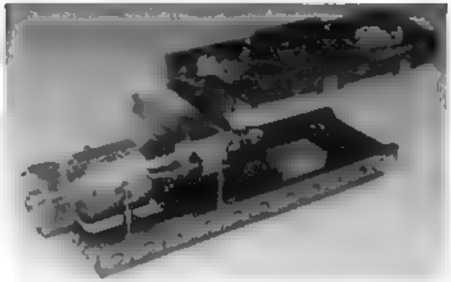

Figure 8. The chassis of a gas turbine-powered locomotive under construction. The model makes high demands on its bearings.

may need brass or bronze bushes fitted. The crankshaft and gudgeon pin will normally be made from hardened steel while some combination of aluminium alloy, cast iron, and steel for the piston/ring/cylinder assembly is a popular choice.

Four-strokes will also require bearings for the cam shaft and any rocker arms as well as a suitable choice of materials for the valve/cylinder head combination and the push-rod guides. Here, steel running in guides of any of the bronzes is a good combination. Diesel engines require a high compression ratio, thus needing a closer fit between piston/ring and cylinder. Luckily, the inherent oiliness of diesel fuel ensures adequate lubrication at this interface. So similar materials to those used in other types of internal combustion engine can safely be employed.

The throttle/carburettor will involve rotating or sliding parts and linkages to levers and radio-control equipment if fitted. On some engines, valve lifters may be needed and for spark-ignition systems a magneto or other means of generating sparks at the right time will be essential. Both will involve not only rotary bearings but also possibly a rotating cam and pair of contacts; steel running in bronze or brass is the norm.

Gas turbines

Gas turbines have special bearing needs due to their very high rotational speeds. Such speeds demand the use of ceramic ball bearings and continuous lubrication, almost invariably provided by passing the fuel/oil mix through the bearing before the fuel enters the combustion chamber. Since the main rotor is the only moving part of the engine, a pair of ceramic bearings placed close to the compressor and turbine is all that is needed, apart from the bearings in an electric fuel pump.

The situation becomes more demanding if the engine is used in a locomotive, as a turbo-prop or in a helicopter. In these cases, a gearbox will be needed with a large reduction ratio and suitable bearings to support the various shafts that carry the gears. Inevitably, steel running in bronze is the preferred solution.

All engines require a high-reliability fuel pump, invariably electrically powered. Motor bearings are usually lubricated for life

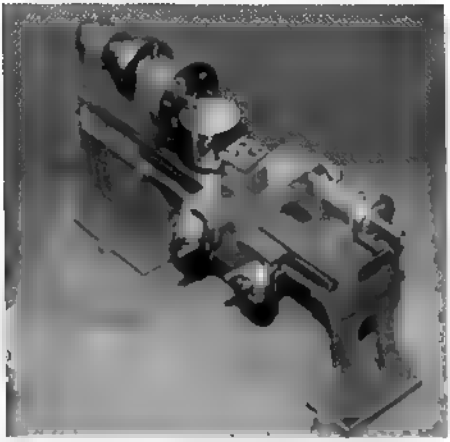

Figure 9. Models of machine tools rarely place heavy demands on their bearings.

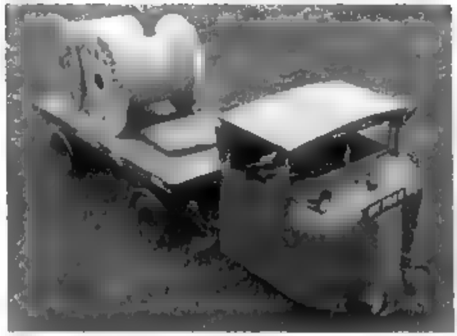

Figure 10. Any model vehicle requires quality steering, suspension and wheel bearings.

and the pump assembly tends to rely on the lubrication qualities of the fuel. Normally, such pumps will be purchased as ready-to-run components.

Other models

Apart from steam and internal-combustion engines, the range of prototypes that model engineers replicate is almost limitless. The remainder of this chapter considers many of the more popular models and looks at their bearing needs.

Machine tools

An increasing number of modellers are choosing to build scale lathes, pillar drills or milling machines, some as working models that cut metal. While such models do not experience the loads placed on full-size machine tools, they do require thought and care in some of the bearing areas, particularly the linear movement of the slides. Miniaturising slides and gib strips is an art in itself but following full-size practice wherever possible is the key. For the rotating bearing, a choice can be made between plain bearings and ball or roller bearings, with needle bearings offering an excellent non-scale alternative due to their space-saving qualities.

Cars and trucks

These vehicles may fall into one of two categories: those that are built to exhibition standards and rarely 'driven' and those that are radio-controlled and are driven or raced, often cross-country. Many are electrically powered but some will use a steam or internal-combustion engine as a source of motive power.

These two areas make very different demands on the bearings employed in their construction. Working models live a hard life, as do their bearings, and some models need to minimise rolling friction. Sealed ball bearings are an obvious choice to avoid contamination from the dust inevitably thrown up when the vehicles are driven, while ball-end servo connections provide precise control of steering and engine throttle control. Working suspension also requires precise

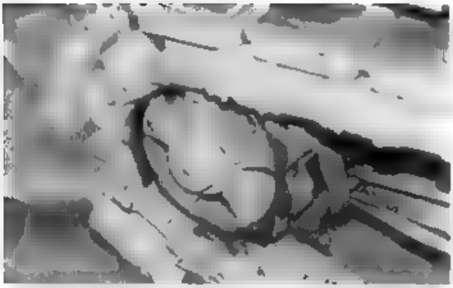

Figure 11. Tracked vehicles tend to operate in poor environmental conditions, placing extra demands on their bearings.

bearings. Shock-absorbers tend to come sealed for life and only relatively few modellers will attempt their construction, which is outlined at the end of Chapter 3.

Tanks and other tracked vehicles

The bearings needed in tanks, cranes and earth-moving vehicles, as well as some tracked trucks and cars, are somewhat different from those used in wheeled vehicles. The main differences between tracked and wheeled vehicles lie in the need for each link of the track to be able to rotate relative to its adjacent links and the comparatively small degree of angular motion. Each link is normally a cast part or, for smaller models, injection-moulded from a tough plastic such as ABS, joined by pins, preferably

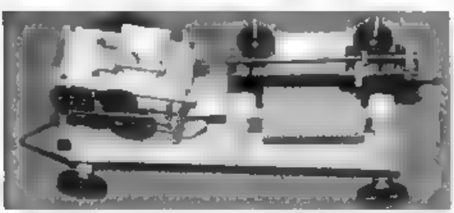

Figure 12. Agricultural machines are mostly made of wood but with metal bearings.

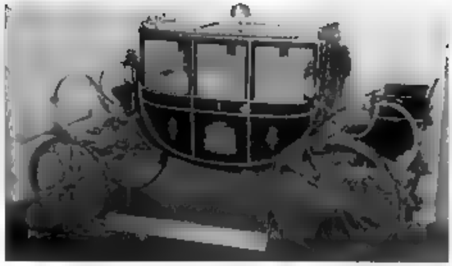

Figure 13. Models of horse-drawn carriages are rarely required to move.

made from stainless steel. Some even involve wooden track links that are glued to a flexible material band that runs around the wheels and sprockets. Tanks are ideal vehicles for operating on rough ground, often dusty or muddy. In addition, they usually have a multiplicity of wheels, most of them independently suspended.

Tanks require a bearing to allow the turret to rotate and likewise cranes require a bearing to allow the jib and cab to rotate. In both cases the speed of rotation is relatively slow and the vertical loadings fairly high; a Lazy Susan or other thrust ball bearing that supports axial loads is an ideal solution. In addition, the gun will need to be able to elevate about its trunion bearings and a crane jib will similarly be required to move up and down while carrying a load. The trunions are almost invariably steel and can run in bronze housings. In addition, a full-size gun designed post mid-nineteenth century will have a built-in recoil mechanism that will have to be reproduced in any scale model, though clearly it will not have to deal with the recoil forces of actually firing its gun!

Horse-drawn vehicles

In the era before steam power most vehicles, such as wagons and carriages, were

principally built from wood, with just the odd metal components. Clearly, the earliest bearing needs were for the wheels and any steerable axle, the former having to perform a much more arduous duty than the latter. By the nineteenth century, wheel bearings for carriages had become well-developed items and provided one of the earliest uses for ball bearings.

However, as horse-drawn models are unlikely to be moved by scale animals, wheel bearings can be simplified and employ plain or ball bearing, depending on the builder's desire to match the prototype in every detail. Thus, while bearings are used in these types of vehicle, even the simplest solution is likely to suffice for this particular application. For models of early prototypes, wood running in wood can be quite satisfactory.

Boats

Many model engineers indulge in building model boats, particularly steam-powered boats where they have to build the engine and boiler themselves. Model boats are generally driven by turning a propeller, though paddle wheels and thrusters are fairly popular alternative forms of drive.

The two areas that are common to almost all powered boats are the need for a waterproof propeller or power-output shaft and a bearing for the rudder which may need to be easily removable. Furthermore, the use of steel shafts leaves a lot to be desired from a rust point of view; stainless steel running in bronze or brass bearings is the preferred solution. In almost all cases, the bearing housings need to be waterproof, to prevent ingress of water into the hull, and rust-proof as well. Thus waterproof glands are often a requirement as well as the bearings themselves.

Figure 14. Model steam-powered boats require water-resistant bearings.

A typical heavy-duty prop shaft consists of a brass prop tube housing a stainless-steel shaft with a Teflon bush and a thread at the propeller end. At the other end is the connection to the engine, with an aluminium ball-race housing and a built-in greasing point containing a shielded ball race. A more economically priced shaft would use plain bushes at each end.

A paddle wheel comprises a large circular framework, on the outer edge of which are numerous blades. In the water, roughly the bottom quarter of the wheel is submerged. Rotation of the paddle wheel produces thrust, either forward or backward as required. More advanced paddle-wheel designs feature feathering blades that keep them nearly vertical when in the water to increase efficiency. Each blade thus requires corrosion-proof bearings with stainless steel running in brass or bronze.

Submarines pose a number of additional problems because they can operate underwater and require sealed rudder bearings as well as similar ones for their hydroplanes. In addition, any push rods that exit the sealed part of the hull need to be water-tight. Thus, the glands fitted to a submarine need to accept an over-pressure of as much as half a

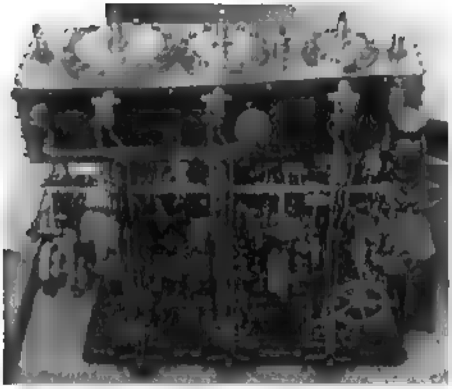

Figure 15. Marine steam engines are usually built with plain rather than rolling bearings.

bar (7 psi) to avoid water ingress through the glands if the boat dives too deep.

Marine steam engines

Marine steam engines can be roughly divided into three groups: those that power paddle steamers, engines that drive one or occasionally more than one propeller, and steam turbines. Clearly one of the most important considerations, from a bearing point of view, is rotational speed. The other factors are the

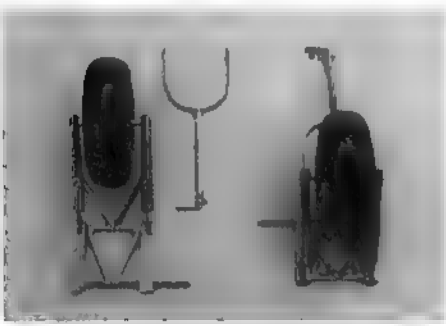

Figure 16. Making a scale retracting undercarriage is a typical task an aero-modeller might ask a model engineer to undertake.

Figure 17. A large-scale model Boeing B29 aircraft retracts its custom-build undercarriage.

need to provide a means of preventing oil contaminating the pond or lake where the boat is being sailed. Of course direct observation or manual lubrication of the moving parts when the boat is sailing is not feasible. With the close proximity to water, corrosion is often an issue, made worse if the water is salty. Thus there is a preference to use stainless steel in any of the bearings if at all possible, to avoid rusting. For prolonged exposure to salt water, Admiralty bronze (nickel-aluminium bronze) was devised to avoid long-term corrosion problems. However, for model use, copper or bronze, and most aluminium alloys as well as stainless steels are quite satisfactory bearing materials.

Model steam turbines lie in a different category to conventional steam engines. There are no reciprocating parts, the rotational speeds are only relatively high and there may be a need for a reduction gearbox to reduce the propeller speed to acceptable levels. Clearly, the use of sealed corrosion-free ball bearings or plastic ball bearings offers many advantages in this application.

Aircraft

There are two areas where model engineers may become involved in model aircraft. The first involves those that are radio-controlled and require complex retractable undercarriages or swing wings. The second is in the

Figure 18. The main rotor head of a radio-controlled helicopter showing the fly bar and swash plate. Such models employ hard-working bearings that need lots of maintenance.

Figure 19. A fairground carousel requires a subtantial thrust bearing to support the rotating parts.

construction of the power plant or even a steam-powered aircraft.

Scale radio-controlled aircraft, particularly those with retracting undercarriages or swing wings, or both, place major demands in terms of their bearings. Undercarriages follow full-size practice, and may be made from aluminium alloy and steel, with suitably bushed parts that interface with steel. Swing wings in particular must be able to move yet still support up to six times the weight of the aircraft in manoeuvres such as loops. With all aircraft, keeping weight to an absolute minimum is always a concern. Thus the use of plastics for swing-wing bearings is an attractive solution.

There have been descriptions of steam-powered models, even radio-controlled, steam-powered aircraft, which make even greater demands on weight reduction. Fortunately, the flight duration of such aircraft is only a few minutes, largely due to the weight of water. Thus the use of the simplest and lightest materials for bearings is at a premium while bearing life is relatively unimportant.

Helicopters and auto-gyros

Radio-controlled helicopters are thought of by many people as something of a mechanical nightmare. They are certainly crammed with gears and shafts, bearings, push-rods and ball joints, swash plates and pitch-changing mechanisms. However, since they are almost invariably built from kits (or ready made) maintenance instructions and spares are generally available from the supplier.

Extensive use is made of ball bearings for the rotating parts such as the gearboxes and rotor bearings, the swash plates are plastic or metal while the control linkages tend to employ ball links moulded from plastic with a brass ball. The pitch control of the main and tail rotor blades may involve plain or ball bearings.

Carousels

In looking at fairground models, roundabouts have a very different bearing requirement to other models as the majority of the structure needs to rotate about its central axis. This requires a thrust race that can support the weight of the structure above it. The bear-

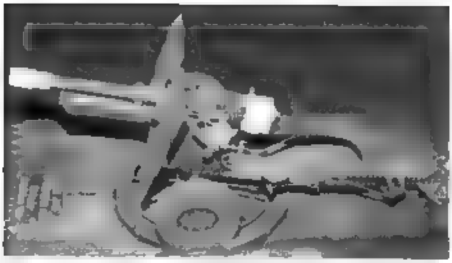

Figure 20. Any artillery piece requires both rotary and linear bearings. Particular attention must be paid to the construction of the recoil mechanism.

ing may take the form of a plain, ball or roller bearing.

Bearings may be acquired off-the-shelf and Lazy Susan bearings are ideal; the largest commonly available has a diameter of 300mm (12"). In addition, of course, the model will need other bearings to move the horses up and down, as well as in the transmission train from the drive motor.

Artillery pieces

From the earliest cannons until the nineteenth century, artillery pieces for use on land and sea employed metal, bronze or gunmetal for the barrel and wood for the majority of the carriage. More recent designs have been made virtually entirely from metal, with quality steel the main material used.

The key parts from a bearing point of view are the trunions, wheel bearings and any recoil mechanism. The first two are rotary bearings and the last one operates in a linear mode, although scale operation is not normally a requirement. Inevitably, the bearings will have to be home-made, except the wheel bearings of a modern artillery piece, which may well employ plain or ball bearings depending on the prototype. Steel trunions and axles running in bronze or brass bearings are ideal.

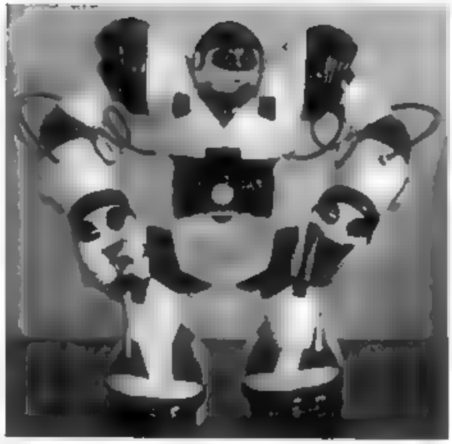

Figure 21. Even the simplest robot will have many moving joints where any stickiness in the bearing is likely to cause problems.

Robots

An increasing number of model engineers are attracted to building and operating robots or maintaining robots they have purchased. Whether trying to mimic the capabilities of humans, just walking or completing a complex task, robots provide a particular fascination.

In all cases, articulating the joints requires a significant number of bearings, as do the linkages and any gear trains. Furthermore, friction needs to be minimised to avoid wasting power and those bearings in the parts of the robot above the centre of gravity will need to be as light as possible. Thus the use of ball or needle bearings is a sensible solution, with plastic ones as an alternative where weight is an issue.

CHAPTER 8

Full-size applications

Introduction

While this book has mostly dealt with the application of bearings to models, there are some classes of 'models' that are actually full size: clocks and watches as well as scientific instruments are examples. Building and repairing the first two are both popular activities and form a thriving sector within model engineering.

In addition, most model engineers enjoy doing some maintenance work on the machine tools in their workshop and a few will even go as far as repairing the electric motors that power them. It is also worth adding the building and restoration of mechanical musical instruments, as well as the making of weather vanes and wind-generators. Thus, this final chapter examines the bearing needs of some of these full-size applications.

However, for those model engineers who become 'diverted' into working on full-size vintage or modern lorries or cars, motor cycles and bicycles, stationary steam engines and steam-powered trains, vehicles and boats, this book can only give the most generalised of assistance, though the bearing principals differ little. Rather it is the size and loadings placed on the bearings themselves that vary.

Machine tools

Refurbishment or restoration of full-size machine tools is a part of most model-engineers' activities. Probably the most common activity is taking up wear in the various slides, followed by the replacement of the headstock bearings. Lubrication, where appropriate, of machine tools is absolutely essential, as is keeping dirt out of all the moving parts.

Gib strips need regular adjustment to take up any wear and ensure there is no slack in the movement of the slide or table. Adjusting a gib requires the slide to be positioned in about the middle of its range of travel. Use a

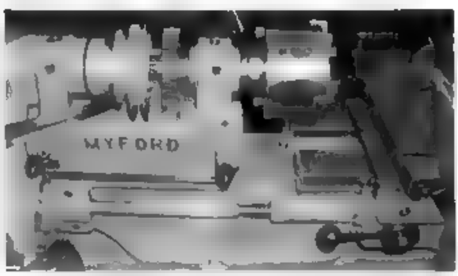

Figure 1 Keeping a modern lathe in tip-top condition requires regular checks, lubrication and adjustment of the myriad bearings.

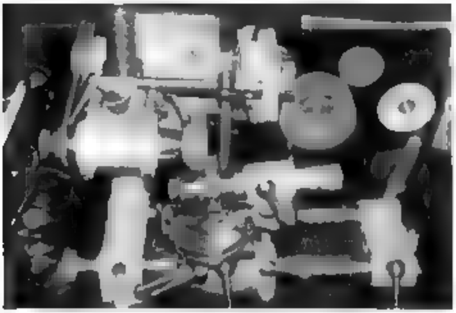

Figure 2. Some model engineers even build their tools, such as the popular Quorn universal tool grinder and cutter.

suitable spanner to slightly loosen each locking nut. Working from the middle of the slide, grip the lock nut with the spanner and tighten the set screw until it is just tight, then back off the screw one quarter of a turn. Holding the screw firmly in position, tighten the lock nut to stop the screw from turning. Now repeat this procedure for all the other adjusting screws.

Finally, check that the slide moves smoothly across its whole range of movement and then grip the slide at both ends and try to move it from side to side. There should be virtually no play. Experience is crucially important and the first-ever attempt to adjust a gib strip may require the adjustment to be repeated several times to get smooth movement without appreciable slop.

The replacement of headstock bearings is a more serious task requiring a degree of skill. Fortunately, it does not often need to be done. There are still a few very old lathes that use plain bearings. Regardless, it is essential to follow the manufacturer's instructions. Companies like Myford list replacement bearings for their headstocks and other parts of their lathes.

Early ML10s use hardened steel spindles that run directly in split cast-iron bearings formed as part of the headstock casting and split on one side with a clamping screw and shims. A pair of tapered roller bearings for a later ML10 will be a relatively expensive purchase but are not too difficult to fit. The same availability applies to the currently produced Super 7 models. On the other hand, replacement white-metal spindle bearings are no longer available for the older ML7, but a kit comprising a hardened steel spindle and a pair of bronze spindle bearings, complete with shims, may be purchased instead as a replacement. As the bearing housings are split and bolted together, disassembly is relatively easy. Take care not to damage the oil reservoir mounted on the top half of the housing.

Watch-maker's and clock-maker's lathes may use coned bearings that are much larger but of similar design to the pivot bearings used in timepieces. In this case, adjustment is normally provided for each of the cones.

Clocks and watches

While people who build clocks and watches fall into the category of modellers, almost invariably the end product is a full-size 'model'. And, of course, both clocks and watches contain many bearings that must operate continuously for years on end without any maintenance.

Furthermore, the amount of power that is available from a spring is very limited, travelling though a considerable gear chain, so the reduction of friction to the absolute minimum is a primary aim of any clock- or watch-builder.

Pivot bearings are the natural choice for most applications as bearings at the balance wheel/pendulum end of the chain. Jewelled bearings may be used to minimise balance

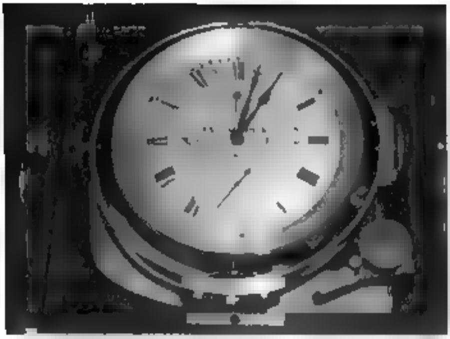

Figure 3. Replicating a marine chronometer requires both clock bearings and precision low-friction bearings for the gimbals.

wheel wear, while bearings at the slower-speed end of the gear train normally make use of relatively simple plain bearings.

For aesthetic reasons, clock plates are almost invariably made from brass plate and the arbors that are fitted between the plates are usually hardened steel, which is invariably well polished.

A few modern designs may employ some ball bearings at the faster end of the gear chain but such designs are few and far between. An example is John Wilding's 'Large balance wheel electric clock' where, as well as a construction manual, a bearing set is also available.

Scientific instruments

The same principles mentioned for clocks and watches apply to those who build replica scientific instruments, although, of course, there is normally no requirement for continuous operation. However, the precision of the bearing may be a critical factor in a working replica of an instrument such as a theodolite. Any slop

Figure 4. Clocks like this Congreve one can be considered as 1:1 scale models and require quality bearings if they are to be good timekeepers.

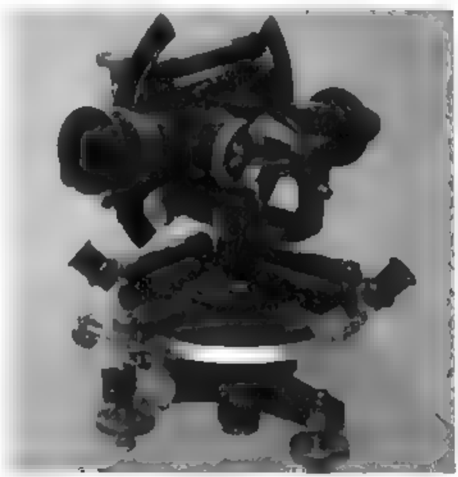

Figure 5. Any scientific instrument requires the most accurate bearings possible.

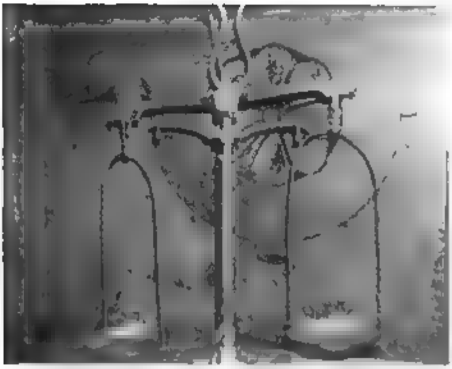

Figure 6. Refurbishing old balance scales requires precision knife-edge bearings.

in the bearings is quite unacceptable.

The main area of interest lies in early instruments that are rarely fitted with other than plain bearings and the amount of actual use such an instrument will receive is small. Thus the production of suitable bearings is not a great challenge, providing that they are an excellent fit, minimising any play in the bearings; most of the bearings in machine tools have similar requirements.

Balance scales

Accurate measurements of mass (weight) can be achieved by using a balance scale. A beam with a pan at each end is set on a knife-edge fulcrum. To reduce friction to an absolute minimum, and for high accuracy, the fulcrum and V-shaped bearing should both be made of hardened steel. A pointer that moves along a centre-zero scale is attached to the beam to amplify any movement of the beam from the horizontal. The item to be weighed is placed in one pan and accurate weights placed in the other until the pointer is at zero. The precision of such scales is highly dependent on the quality of the V-shaped bearing.

Figure 7. Easy access to this particular electric motor makes replacing the bearings a relatively straightforward task.

Electric motors

The power source of almost every machine tool in the average workshop is an electric motor that will inevitably need mechanical attention from time to time. It is usually the bearings that require replacement on induction and stepper motors, though brushes may also cause problems on commutator motors.

The replacement of these bearings is a relatively straightforward task, especially as replacement bearings may readily be obtained from local bearing stockists listed in Yellow Pages or by mail order on the Internet.

Of course, special care is required when removing the old bearings and it is essential to avoid damaging any wiring that forms part of the armature, field winding or commutator if employed.

For motors fitted with plain bearings, almost invariably manufactured from sintered bronze impregnated with oil, two key indicators that the bearings may need to be changed are play in the output shaft and unusual noises when the motor is running. Plain bearings are quite tolerant of a fair degree of wear unless there has been a problem with their lubrication. On some plain bearings an oil-impregnated felt pad is also fitted. Additional machine oil, or in the case of motors running faster than 3,000

rpm, a lighter oil such as sewing machine or 3 in 1 oil may be used to top up the lubricant. However, it is very important that any bearings close to the commutator are not over-lubricated as any oil leaking onto the commutator will ruin its performance.

Motors with ball races inherently run more noisily than those with plain bearings. To check the bearings, rotate the shaft slowly by hand, feeling for any sign of roughness and, of course, for any sign of play. The feel of a ball bearing that is coming to the end of its life is very distinctive and may have been caused by fatigue cracks or the ingress of dust. Replacement of the bearing may be an option if the old bearing is accessible and can safely be removed without damaging the rest of the motor.

Removing the worn bearing may cause further damage to it once the armature and its shaft have safely been removed from the motor casing. On occasions, if an anaerobic adhesive has been used, carefully heating the bearing to around 150°C should break the adhesive bond and allow the bearing to be removed while the adhesive is still hot.

A replacement bearing should be readily available but care is essential when re-fitting any bearing with an interference fit; the inner race must be pressed onto the shaft as shown in Figure 8, using a touch of grease to ease its progress.

Very occasionally, the outer race may have become slightly loose in its housing and continuous use will cause the race to rotate in its housing, causing wear. If the amount of wear is small, an anaerobic adhesive may be used to fill the gap. But if the wear is serious, the use of steel-reinforced epoxy or enlarging the housing and fitting a bush, or possibly a bearing with a slightly increased outside diameter, are the only practical alternatives.

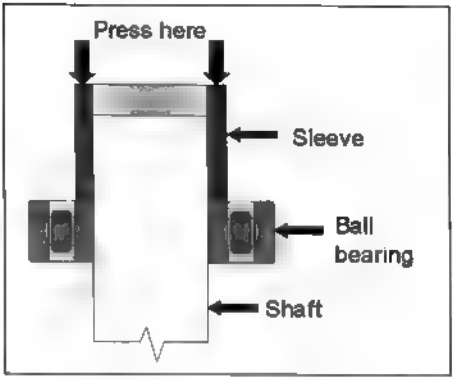

Figure 8. Use a sleeve pressing on the inner race to push the bearing onto the shaft.

Commutators

A commutator and its brushes may be thought of as a particular type of bearing used only on some electric motors and generators. The most common material pairs used are carbon brushes with a copper commutator or copper brushes with a brass commutator. In all cases, the commutator is part of the rotating assembly and the brushes are spring-loaded to provide electrical contact.

Weather vanes and wind-generators

Many model engineers enjoy building a weather vanes to fit on their property, often with a cut-out of their favourite locomotive, traction engine or steam lorry as the vane. And as no-one wants to climb onto the roof to maintain the bearings, they have to meet three main criteria:

1. Low friction
2. Lubricated for life
3. Weather-proof.

These requirements can be met by sealed, lubricated-for-life ball bearings. The other ob-

Figure 9. A classic model engineer's wind vane showing a Pacific locomotive outline.

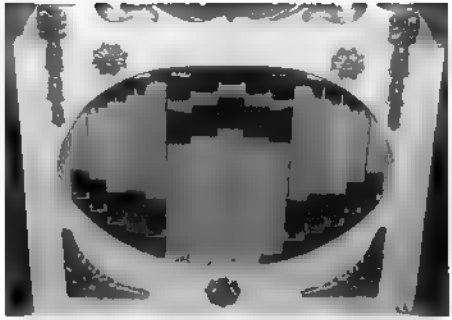

Figure 10. A small organ, typical of musical instruments built by model engineers.

vious alternative is plastic ball bearings.

As the world in general recognises the need to become greener, some model engineers may become involved in building home-made wind-generators. Of course, such an installation will usually require planning permission but, as electricity prices rise, the economic benefits increase and the incentive to generate power from re-usable sources will increase.

Bearing-wise, the main shaft will need long-life, low-friction, maintenance-free bearings that can support the load of the main rotor. The blades themselves must be able to alter their angle depending on the wind speed and will require bearings in their hubs. For the home-constructor, sealed ball or roller bearings are the obvious choice. The generator itself, or alternator, will inevitably come fitted with its own bearings.

Mechanical musical instruments

Building and restoring hurdy-gurdies, barrel organs and musical boxes has always been a pastime for some model engineers, fascinated with the mechanical production of music. While often a fair number of bearings is involved, and the occasional gearbox, there are rarely any severe demands placed on the bearings, except the need to keep friction to a minimum where a clockwork drive is involved. The choice of whether to use plain or ball bearings will largely depend on the prototype's bearings.

Other full-size applications

Full-size cars and trucks, whether vintage or modern, make heavy demands on their bearings and, in most cases, work involves replacement with off-the-shelf roller or ball bearings. Older vehicles may have some plain-bearing applications, such as the big-end bearings of vintage internal-combustion engines that will require re-metalling using Babbitt metal. Static internal-combustion engines, motor cycles, tricycles and bicycles generally fall into the same category.

Static steam engines and steam-powered trains, traction engines, vehicles and boats require a different approach, as most of the bearings will have been made by the manufacturer and replacements will generally have to be hand-made

Conclusions

This book attempts to provide an understanding of many of the bearing problems likely to be found by the average model engineer, whether working with a diverse range of models or a selection of full-size applications. Clearly there is a limit to the amount of detail that can be included in a volume of this size.

Much in-depth information is available on the Internet and, where model engineers feel they cannot make bearings in their workshops, a huge range of different types of bearing is available from the nearest bearing shop, which can be located through Yellow Pages, or by purchasing from one of the many Internet suppliers. A list of useful contacts is given overleaf.

For model designers, it is hoped that this volume will provide some insight into the wide range of choices available when thinking about bearings as well as the relative advantages and disadvantages of each potential solution.

Choosing which type of bearing to use often involves a series of trade offs between a number of conflicting factors. These include: staying faithful to the original prototype, following an existing design, using readily available bearings, often in the modeller's spares box, the skill required to build or fit the bearings and their cost. As in every area of engineering, knowledge allows a more informed choice to be made.

List of useful contacts

Bearingboys Ltd, Unit 1, Ashford Rd, Bethersden, Kent, TN26 3AT, UK
<http://www.bearingboys.co.uk>

Bearings2you.com, ESK Centre, Whitebridge Way, Stone, ST15 8JS, UK
<http://www.bearings2you.com>

Boca Bearing Company, 755 NW 17th Ave, #107 Delray Beach, FL 33445, USA
<http://www.bocabearings.com>

Fish4Parts Limited, 72 Liverpool Street, Salford, M5 4LT, UK
<http://fish4parts.co.uk/Mechanical.80/Bearings.1093>

Midland Bearings Ltd, Building 33, Second Av,e, Pensnett Trading Estate, Kings-winford, West Midlands, DY6 7UG, UK
<http://www.midlandbearings.com>

NOMA IKS Corp, 1555 W. Rosecrans Av,e, Gardena, CA 90249, USA
<http://www.iksbearing.com/index.html>

Oilite Bearings Ltd, Elton Park Works, Hadleigh Road, Ipswich, IP2 0AS, UK
<http://www.oilitebearings.com>

Polly Model Engineering Ltd, Bridge St, Long Eaton, Nottingham, NG10 4QQ, UK
<http://www.pollymodelengineering.co.uk>

RiteTime Publishing Ltd, 18 Woolmer Way, Bordon, Hants, GU35 9QF, UK
<www.ritetimepublishing.com>

Schaeffler (UK) Ltd, Forge Lane, Minworth, Sutton Coldfield, B76 1AP, UK
<http://www.schaeffler.co.uk>

Simply Bearings Ltd, 21 Stonecross Lane, Lowton, Warrington, WA3 2SD, UK
<http://www.SimplyBearings.co.uk>

SKF (UK) Ltd, Sundon Park Road, Luton, Bedfordshire, LU3 3BL, UK
<http://www.skf.com>

Timken UK Limited, Key Industrial Park, Fernside Road, Willenhall, West Midlands, WV13 3YA, UK
<http://www.timken.com>

UK Bearings Ltd, Unit 17 Premier Trading Estate, Leys Road, Brierley Hill, West Midlands, DY5 3UP, UK
<http://www.ukbearings.co.uk>

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